Journal

of

THE ROYAL AERONAUTICAL SOCIETY

APRIL 1959

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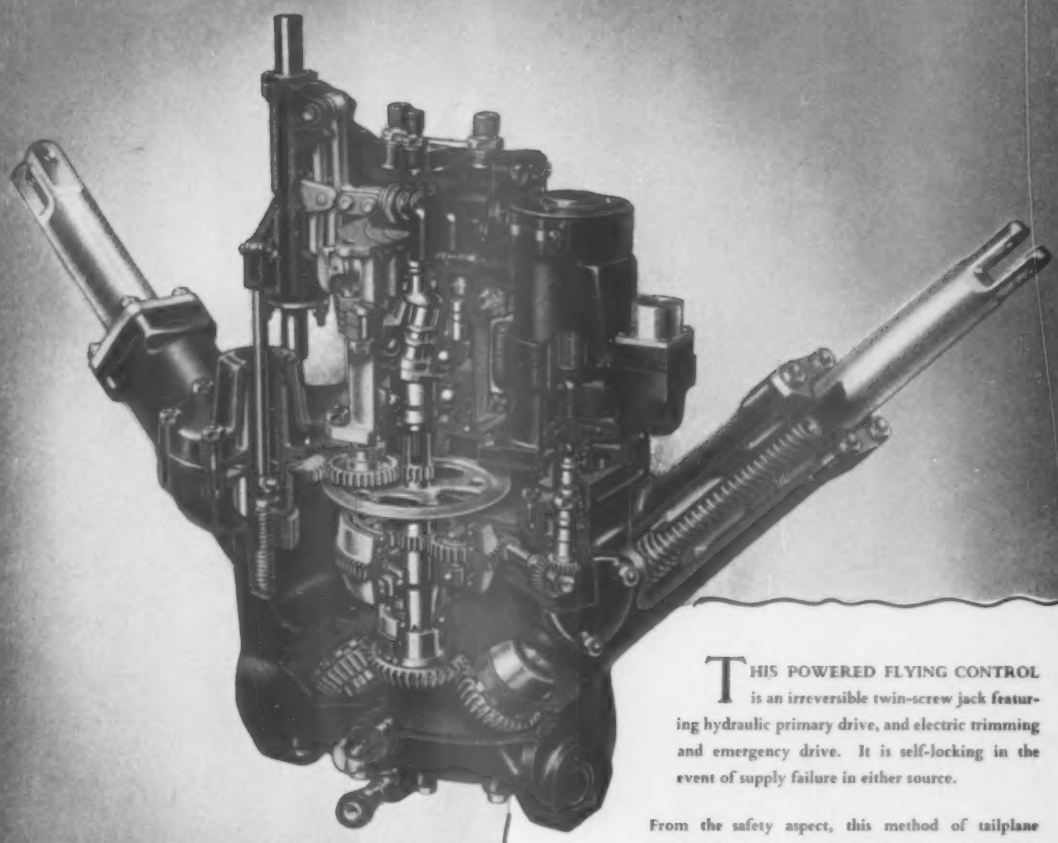

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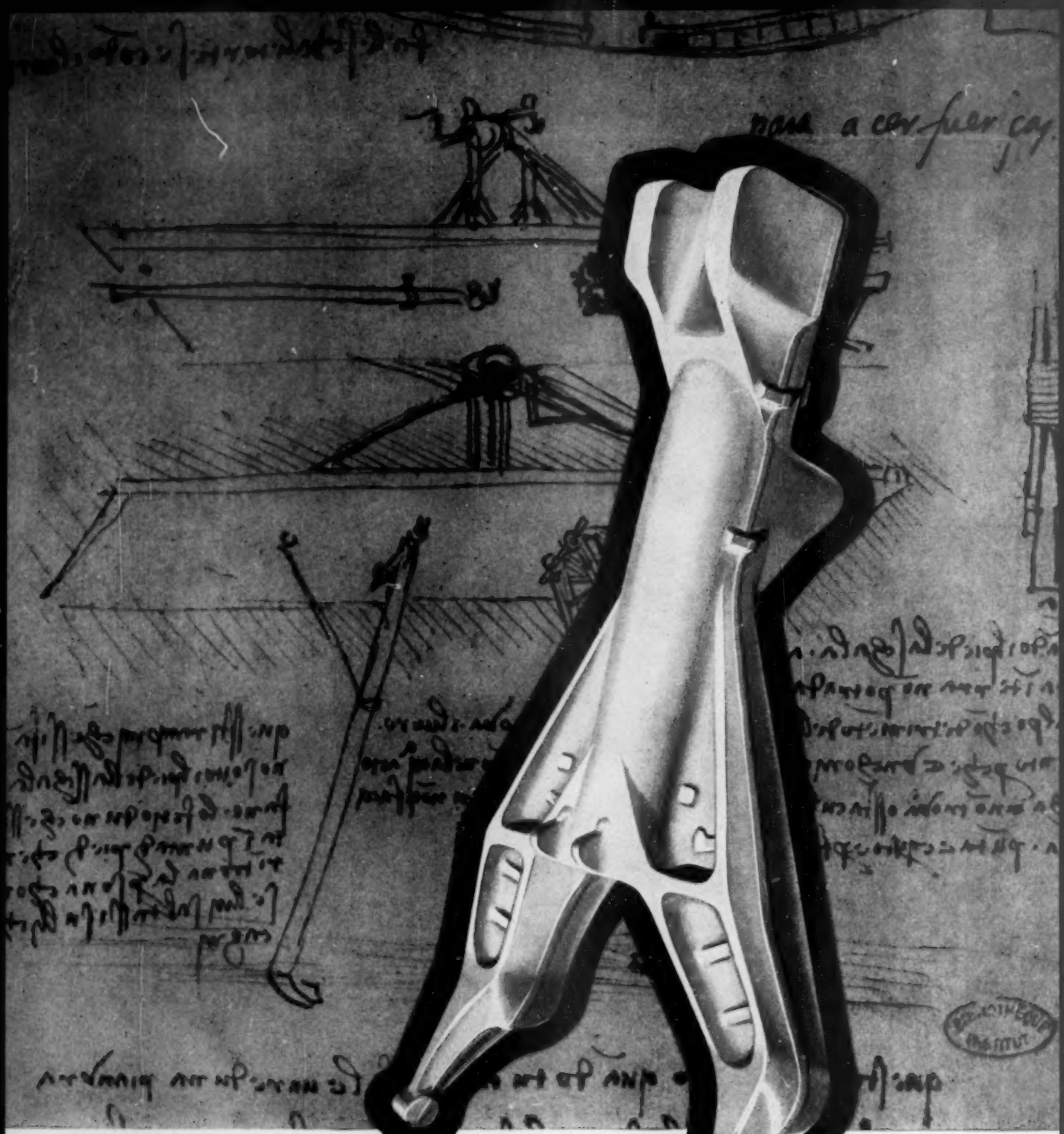

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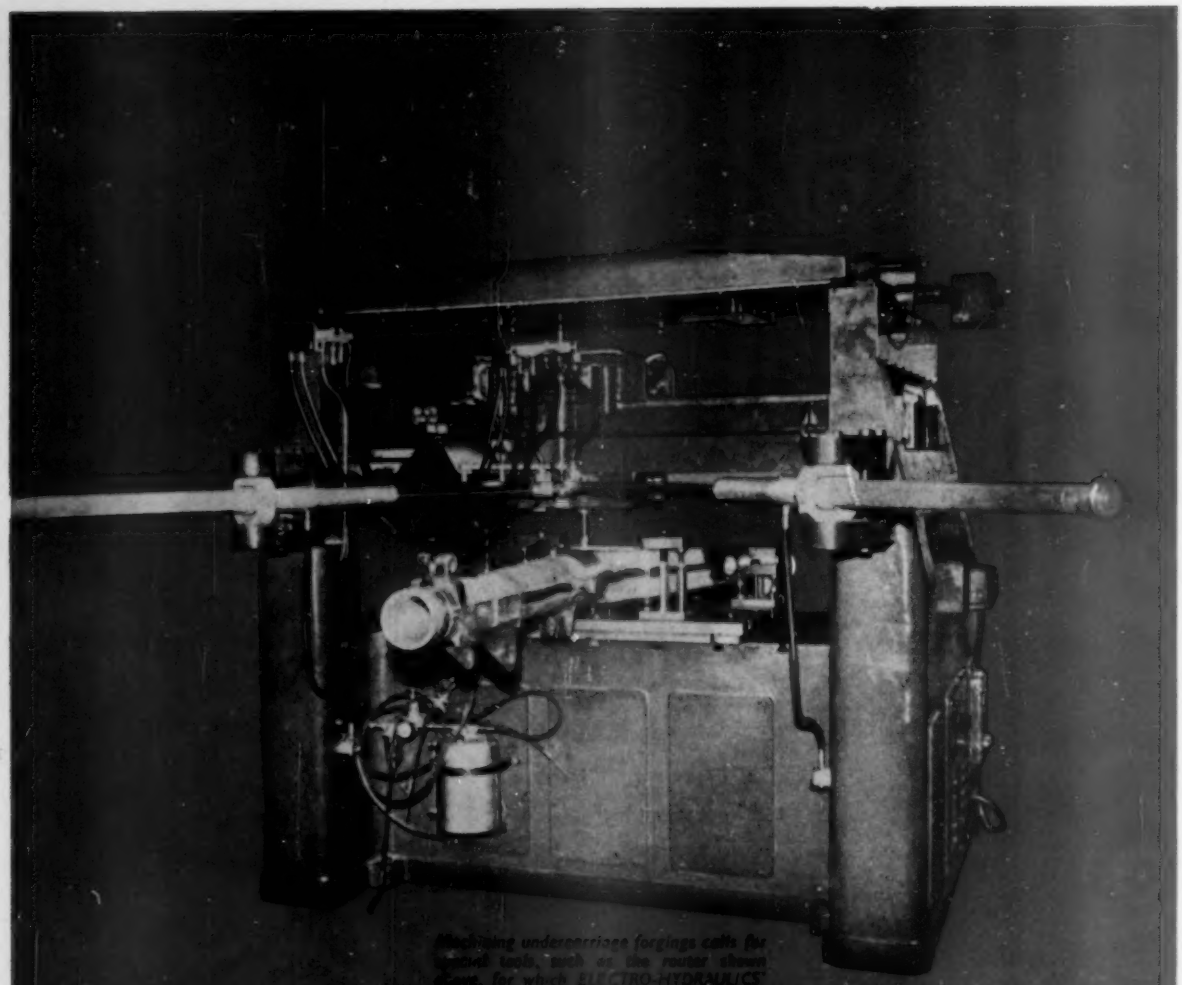

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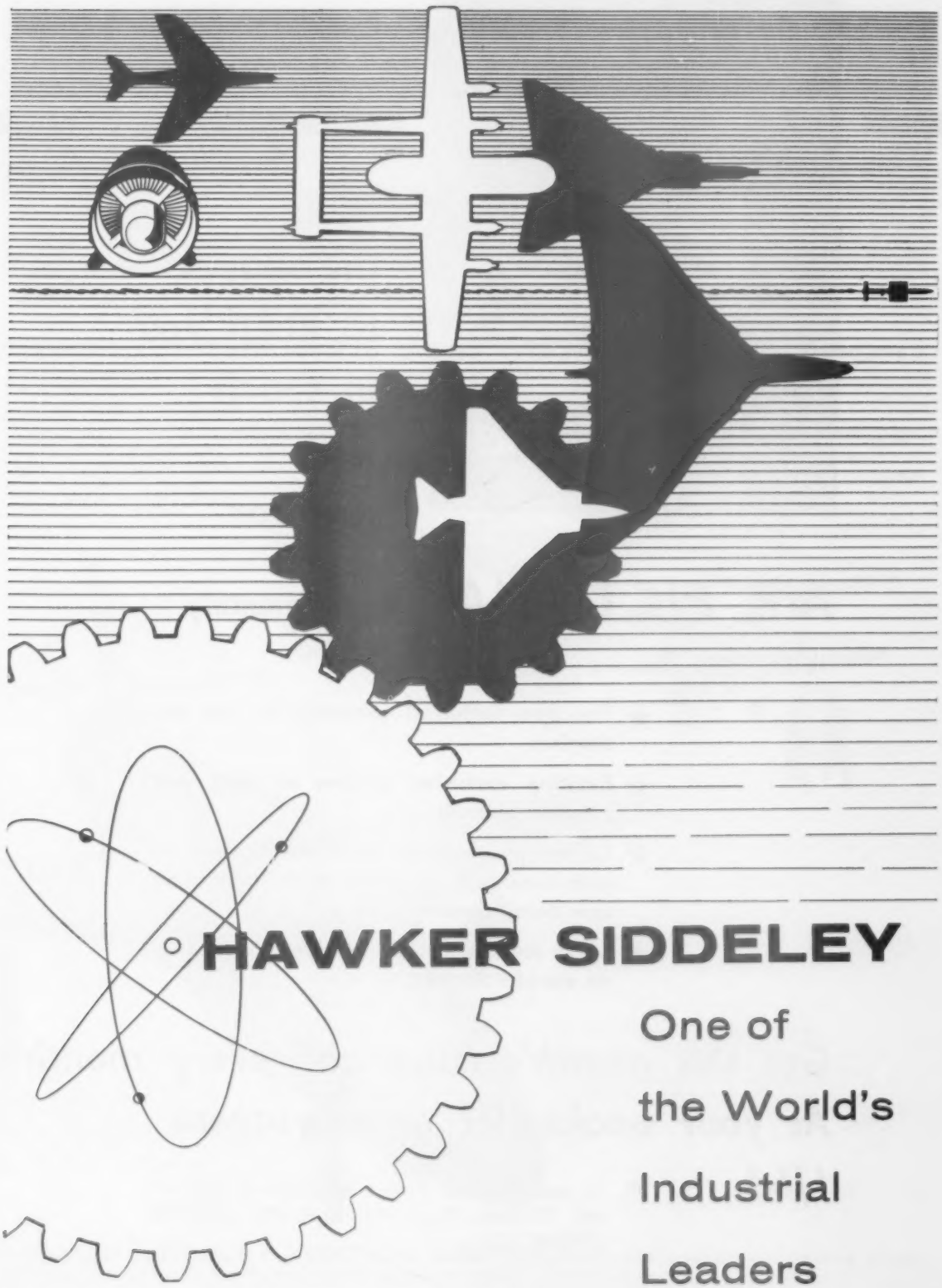
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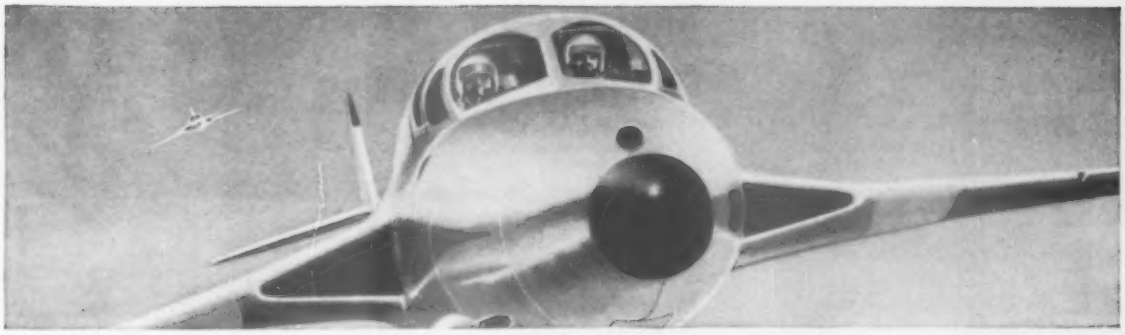

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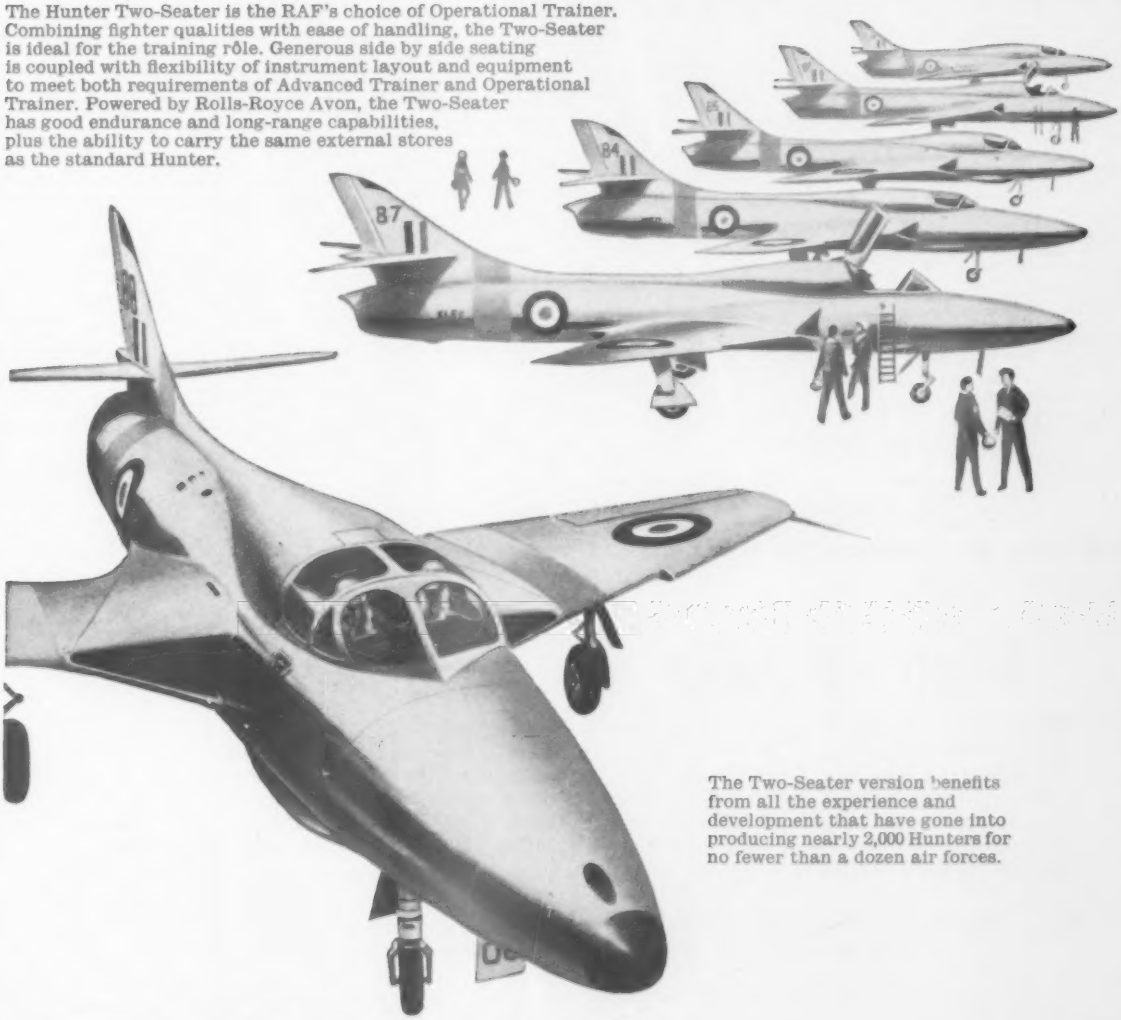

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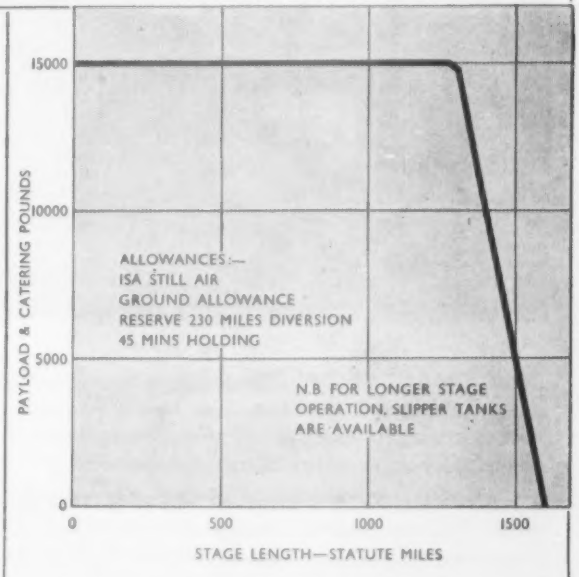

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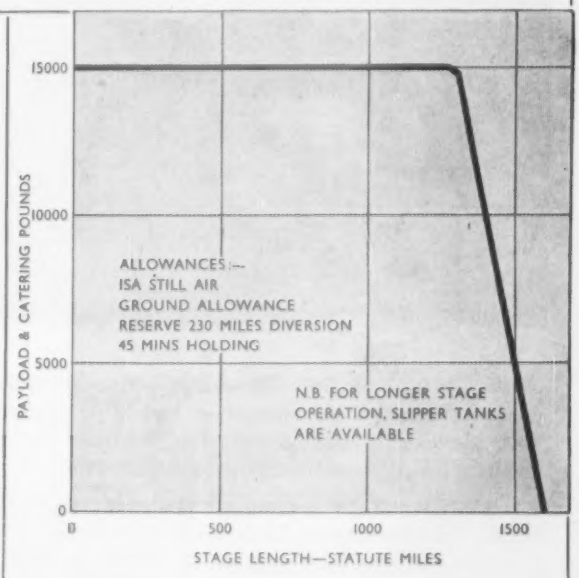

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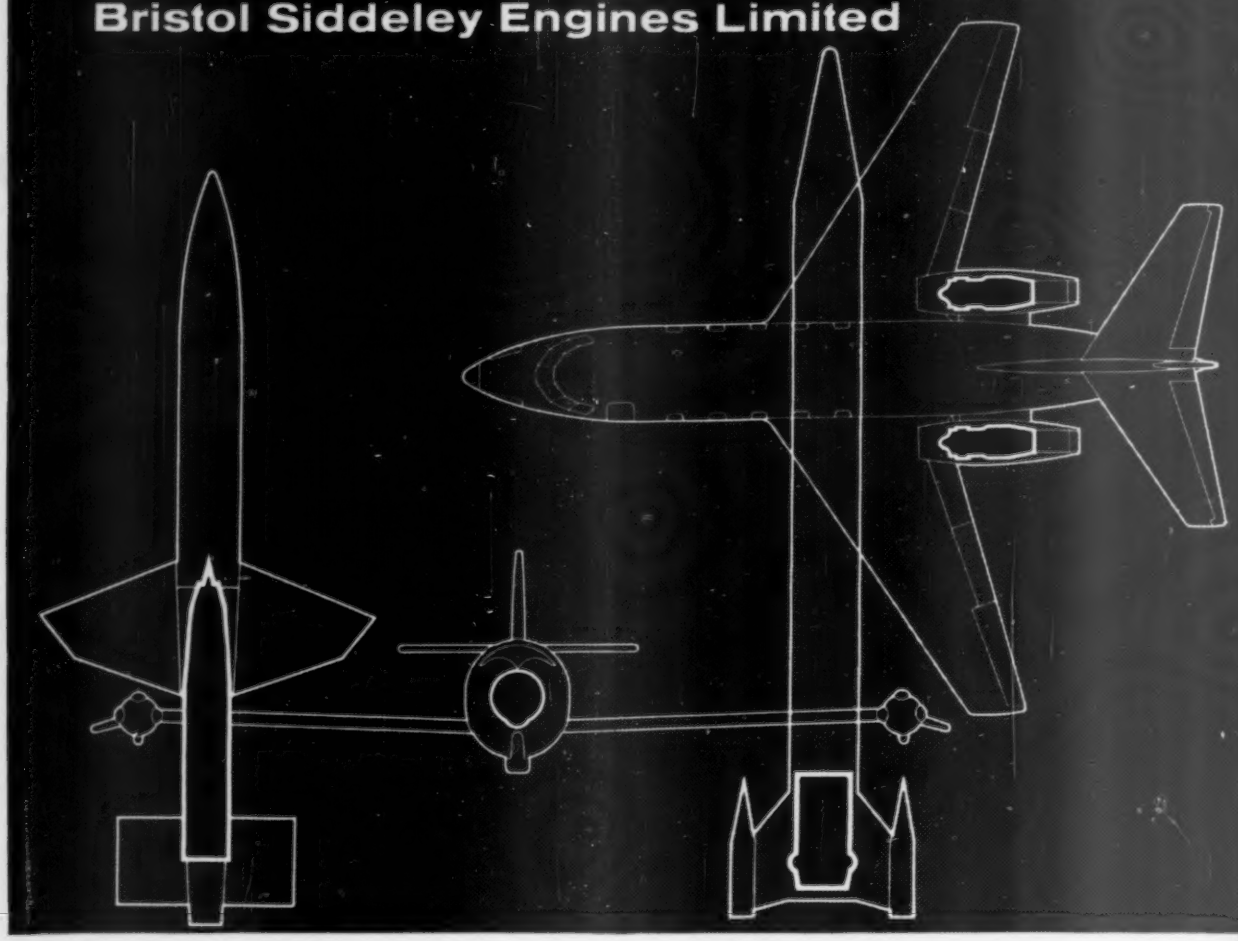

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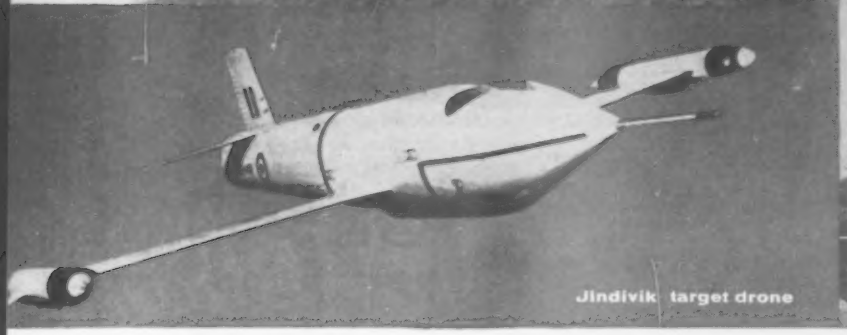

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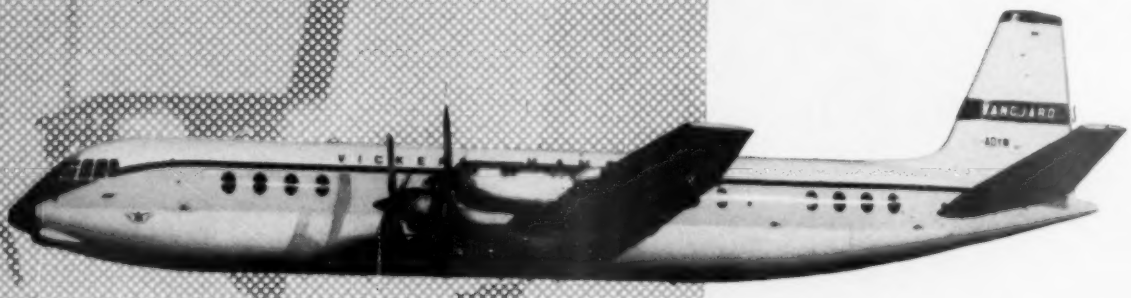

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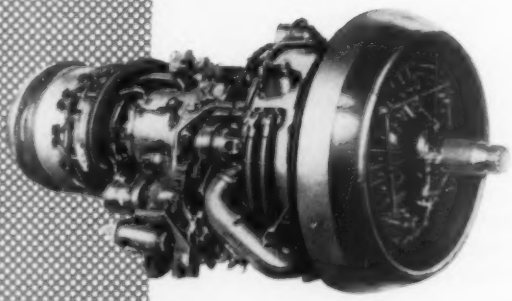

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All communications for publication in the JOURNAL *should be addressed to the Editor,* JOAN BRADBROOKE, *A.R.Ae.S.; all communications on general matters affecting the Society should be addressed to the Secretary,* A. M. BALLANTYNE, *T.D., B.Sc., Ph.D., Hon.F.C.A.I., F.I.A.S., F.R.Ae.S.*

None of the papers or paragraphs must be taken as expressing the opinion of the Council of the Royal Aeronautical Society unless otherwise stated.

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AGARDograph No. 27

AIR INTAKE PROBLEMS IN SUPERSONIC PROPULSION

***Edited by* JEAN FABRI**

Interference between the different parts of the engine cannot be neglected in design of air intakes, and the testing of the intake alone, without a study of the overall operation of the engine, is apt to lead to wrong estimations of performance. It was the aim of the AGARD **Combustion and Propulsion Panel** to emphasise this aspect of the air intake problem by inviting four scientists—P. CARRIÈRE, D. D. WYATT, A. FERRI and L. VIAUD, specialists in the air intake field—to define their viewpoint on the air intake-engine matching problem.

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AGARDograph No. 28

HIGH TEMPERATURE EFFECT IN AIRCRAFT STRUCTURES

Edited by* N. J. HOFF, *Member, Structures and Materials Panel of AGARD; Head of the Division of Aeronautical Engineering, Stanford University

It was decided that the dissemination of this information could best be accomplished by persuading outstanding scientists and engineers to survey a number of distinct portions of the subject and to write review articles to be incorporated in the book as individual chapters. With the advice of various European experts, Dr. Hoff has been able to achieve his aim, and the resulting volume argues well for the development of an increased effort in research on the structural implications of high temperatures.

Available now **Price 70s net ($12)**

AGARDograph No. 31

EXPLOSIONS, DETONATIONS, FLAMMABILITY AND IGNITION

by* S. S. PENNER, *Professor of Jet Propulsion, California Institute of Technology, and* B. P. MULLINS, *National Gas Turbine Establishment Farnborough.

An unusual feature of this monograph is that the same material has been discussed by the two authors from entirely different but complementary viewpoints—the one analytical, the other semi-empirical and practical. In Part I S. S. PENNER gives some emphasis to the powerful technique in theoretical combustion research introduced by Schvab and Zelovich.

In Part II (B. P. MULLINS) a thermal hypothesis, which might be described as a generalisation of Semenov's conception of the ignition temperature, is shown to be of great use in predicting combustion phenomena such as flammability limits and flash-points and the effects of diluent gases on limiting combustion processes.

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AGARD Eight-Language AERONAUTICAL DICTIONARY

Edited by* GEORGES H. FRENOT, *Member of the AGARD Documentation Panel, Technicien-Chef de Travaux d'Etudes et de Fabrications, Chef du Groupe Exploitation Documentaire, Service de Documentation et d'Information Technique de l'Aeronautique.

The presentation is new, inasmuch as each term and its definition is found in all the languages covered by the dictionary—English, French, German, Dutch, Italian, Russian, Spanish and Turkish—under the same classification number. Also, an alphabetical index given for each language enables the number of the desired term and the page where this term is to be found, followed by its foreign equivalents with their definitions, to be determined.

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NOTICES

School Holidays in France

Following the arrangements made in the past few years for school holidays in France, the Society has again received an invitation from Monsieur J. Jarry, President of Association Française des Ingénieurs et Techniciens de l'Aéronautique, to continue the arrangement. During his recent visit to London he reported that the scheme was working very well, resulting in many happy friendships among children and parents of both countries. Those members of the Society who are interested should either write direct to M. Jarry or to the Secretary of the Society, giving full particulars of age of the child, or children, and the dates on which they would like to exchange holidays. The address of A.F.I.T.A. is:—6 Rue Cimarosa, Paris XVI.

All-Day Discussion on the Structural Effects of Kinetic Heating

Admission to the All-Day Discussion on the Structural Effects of Kinetic Heating on Tuesday 21st April 1959 *will be by special ticket only* for members *and* non-members. Applications for tickets should be made to the Secretary and until the 14*th April* will be issued to members only. Thereafter any seats available will be issued to non-members in strict rotation.

The All-Day Discussion will begin at 9.45 a.m. at the Institution of Mechanical Engineers, Birdcage Walk, London, S.W.1. Four introductory papers will be given: Factors Affecting Choice of Materials by W. G. Heath; Design of Transparencies by Dr. J. S. Przemieniecki; Some Practical Aspects of Kinetic Heating Calculations by C. L. Bore; Advantages and Limitations of the Use of Models by A. J. Sobey. M. B. Morgan, Deputy Director, R.A.E., will take the chair.

Lectures by Professor J. W. Miles

The Royal Aeronautical Society and The University of London announce two lectures by Professor John W. Miles of the Department of Engineering, University of California, under the sponsorship of the Advisory Group for Aeronautical Research and Development of N.A.T.O. They are:

"SUPERSONIC PANEL FLUTTER," under the Chairmanship of Professor H. B. Squire, M.A., F.R.S., F.R.Ae.S., to be given on **FRIDAY 17th APRIL at 6 p.m. at Imperial College, Roderick Hill Building (Aeronautics Dept. Room 266),** Prince Consort Road, London S.W.7. (Nearest Underground Station, South Kensington.)

"THE GENERATION OF SURFACE WAVES BY SHEAR FLOWS" (with application to flutter and aerodynamic noise), under the Chairmanship of Professor A. D. Young, M.A., A.F.I.A.S., F.R.Ae.S., to be given on **FRIDAY 24th APRIL at 6 p.m. at Queen Mary College, Mile End Road, E.1.** (Nearest Underground Stations Mile End and Stepney Green.)

Admittance to these lectures is free and no tickets are required.

Acknowledgments

The Council wish to thank Mr. J. R. Ewans (*Associate Fellow*) for copies of "Jahrbücher den deutschen Luftfahrtforschung" 1940, 1941 and 1942, and "Ringbücher der Luftfahrttechnik" volumes 1, 2, 3 and 5.

They also wish to thank the Librarian of C.I.B.A. (A.R.L.) Ltd., Cambridge, for presenting sundry copies of "Luftfahrtforschung" to the Library.

A General Meeting of the Society—4th May

A General Meeting of voters of the Society will be held on Monday 4th May at 6 p.m. at 4 Hamilton Place, to consider proposed changes in the By-Laws of the Society.

Members have already been sent the Calling Notice for this meeting and the proposed changes in the By-Laws.

Annual General Meeting—7th May 1959

Notice is hereby given that the Annual General Meeting of the Royal Aeronautical Society, with which is incorporated the Institution of Aeronautical Engineers, will be held on Thursday 7th May 1959, at 5.30 p.m., in the Offices of the Society, 4 Hamilton Place, London W.1.

AGENDA

1. To read the Notice convening the Meeting.
2. To receive and deliberate upon the Report of the Council on the state of the Society and the Balance Sheet and Income and Expenditure Accounts of the Royal Aeronautical Society and Aeronautical Trusts Limited for the year ended 31st December 1958.
3. To receive the names of those elected to Council for the years 1959-1962.
4. To announce the names of Fellows elected by the Council in accordance with By-Law 4.
5. To elect the Auditors for the year 1959.
6. Any other business.

By Order of the Council,
A. M. BALLANTYNE,
Secretary.

Note: In accordance with the By-Laws any member whose subscription has not been paid before the first day of April is not entitled to vote.
Light refreshments will be served after the meeting.

The Royal Aero Club Cocktail Party for Lord and Lady Brabazon

To celebrate the fiftieth anniversary of the first officially recognised aeroplane flight by an Englishman in this country, which was made by Mr. J. T. C. Moore-Brabazon (now Lord Brabazon) on the 2nd May 1909, a Cocktail Party to Lord and Lady Brabazon is to be held on the 29th April 1959 at Londonderry House, 19 Park Lane, London W.1, from 6 p.m. to 8 p.m.

Tickets, £1 each, may be obtained from the House Secretary, The Royal Aero Club, 119 Piccadilly, London W.1, and are available to all who may wish to pay their respects to Lord Brabazon. Ladies are welcome. As accommodation is limited to 450 persons, early application for tickets is advisable.

Membership of The Institute of the Aeronautical Sciences and Relief for Purposes of United Kingdom Income Tax

The Society has been advised that the Institute of the Aeronautical Sciences Inc., New York, has been approved for purposes of Section 16, Finance Act, 1958. This means that members resident in the United Kingdom who are also members of the American Institute (I.A.S.) may obtain relief on the subscriptions paid to that body from the tax year 1958/9 onwards. Those entitled to claim such relief should ask their local Inspector of Taxes for Form No. P357. The conditions set out in the Chief Inspector's letter dated 3rd January 1959, reference C.I/SUB/523/LACH, are exactly the same as those applicable to the Society and were published in the February Journal (p. XII).

DIARY

LONDON

17th April

JOINT LECTURE WITH UNIVERSITY OF LONDON UNDER THE SPONSORSHIP OF AGARD—Supersonic Panel Flutter. Professor J. W. Miles of the University of California. **Imperial College, Roderick Hill Building (Aeronautics Dept., Room 226) at 6 p.m.** *See separate Notice.*

21st April

ALL DAY DISCUSSION ON THE STRUCTURAL EFFECTS OF KINETIC HEATING. Institution of Mechanical Engineers, Birdcage Walk, S.W.1. 9.45 a.m. **Admission by special ticket only.** *See* special notice.

23rd April

MAIN LECTURE—**Cancelled.**

24th April

JOINT LECTURE WITH UNIVERSITY OF LONDON UNDER THE SPONSORSHIP OF AGARD—The Generation of Surface Waves by Shear Flows (with application to flutter and aerodynamic noise). Professor J. W. Miles of the University of California. **Queen Mary College, Mile End Road, at 6 p.m.** *See separate Notice.*

27th April

LECTURE★—Basic Principles of Radar with Particular Reference to Aircraft and Missile Applications. F. D. Boardman. Institution of Civil Engineers, Great George Street S.W.1. 6 p.m. (Tea at 5.30 p.m.)

5th May

LECTURE—The Potential Use of Aircraft for Agricultural Purposes (with particular reference to New Zealand). R. H. Scott. Library, 4 Hamilton Place. 7 p.m.

14th May

FORTY-SEVENTH WILBUR WRIGHT MEMORIAL LECTURE—Managing Aviation Technologies. C. J. McCarthy. Institution of Mechanical Engineers, Birdcage Walk, S.W.1. 6 p.m. (Tea at 5.30 p.m.)

★ Arranged by Astronautics and Guided Flight Section.

BRANCHES

15th April

Brough—Annual General Meeting. Lecture Room, Flying Club, Brough. 5.10 p.m.

Coventry—Annual General Meeting. Wine Lodge, Corporation Street. 7.30 p.m.

16th April

Derby—The Development of Instrument Flight Control of Transport Aircraft. A. M. A. Majendie. Hucknall. 5.30 p.m.

22nd April

Hatfield—Discussion Evening. de Havilland Restaurant. 6.15 p.m.

23rd April

Preston—Annual General Meeting and Film Show. R.A.F. Association Hall, Preston. 7.30 p.m.

29th April

Christchurch—Annual General Meeting and Film Show. King's Arms Hotel. 7.30 p.m.

Weybridge—Annual General Meeting. Apprentice Training School, Vickers-Armstrongs (Aircraft) Ltd. 6.10 p.m.

5th May

Luton—Aircraft Carriers. J. C. Lawrence. Napier Senior Staff Canteen, Luton Airport. 6.15 p.m.

7th May

Cambridge—Some Aspects of Blind Landing Technique. W. J. Charnley. No. 1 Lecture Theatre, Cambridge University Engineering Laboratories. 8.15 p.m.

11th May

Glasgow—Philosophy of Gas Turbine Design. A. L. Brown. Royal College of Science and Technology. 7.15 p.m.

Halton—Some Aspects of Nuclear Propulsion. Sqd. Ldr. G. R. Candy. Branch H.Q., R.A.F. Halton. 6.45 p.m.

13th May

Chester—Annual General Meeting and Film Show. Lecture Theatre, Grosvenor Museum. 7.30 p.m.

Southend—Space Travel. Dr. G. S. Brosan. Labour Hall, Boston Avenue. 7.30 p.m.

27th May

Hatfield—Annual General Meeting. de Havilland Restaurant. 6.15 p.m.

28th May

Southend—Film Show. Labour Hall, Boston Avenue. 7.30 p.m.

FORTY-SEVENTH WILBUR WRIGHT MEMORIAL LECTURE

The 47th Wilbur Wright Memorial Lecture will be given by C. J. McCarthy, F.I.A.S., Chairman, Chance Vought Aircraft, Inc., on "Managing Aviation Technologies," on Thursday 14th May, at the Institution of Mechanical Engineers, Birdcage Walk, S.W.1., at 6 p.m. (Tea 5.30 p.m.)

NEWS OF MEMBERS

D. L. BROWN (*Associate Fellow*), formerly Principal of the School of Gas Turbine Technology has joined Smiths Aircraft Instruments Ltd., as Deputy Manager of the Research Department.

J. T. BURR (*Associate Fellow*), formerly with Bristol Aircraft Ltd., is now Mathematics Master at Wellington College.

C. D. CARMICHAEL (*Associate Fellow*), formerly Assistant Chief Engineer (Piston Engine Division), D. Napier and Son Ltd., is now Assistant Chief Engineer (Deltic and Turbo-blowers).

R. H. CHAMBERLIN (*Associate Fellow*), formerly Chief Designer of the Aero Gas Turbine Division of D. Napier and Son Ltd., has been appointed Chief Engineer.

G. E. CLIFFORD (*Associate Fellow*), formerly Production Superintendent (Turbo-blowers), D. Napier and Son Ltd., is now Chief Development Engineer (Turbo-blowers).

L. H. ELFORD (*Associate Fellow*), formerly Head of Turbo-blower Department, D. Napier and Son Ltd., is now Assistant Chief Designer (Turbo-blowers).

D. P. D. FERGUSON (*Associate Fellow*), formerly Aero Gas Turbine Design Section Leader, D. Napier and Son Ltd., is now Assistant Chief Engineer (Aero).

LIEUT. CMDR. S. N. GARBUTT (*Associate*), formerly at the Proof and Experimental Establishment, Pendine, is now with the Armament Research and Development Establishment, Fort Halstead.

S. SCOTT HALL (*Fellow*), formerly Scientific Adviser to the Air Ministry has been appointed Head of the United Kingdom Ministry of Supply Staff in Australia (Melbourne).

F. R. HEATH (*Associate Fellow*), formerly Mechanical Research Engineer, D. Napier and Son Ltd., is now Chief Development Engineer (Aero).

P. HOLLENBERG (*Graduate*), has left Avro Aircraft Ltd., and is now a Performance Engineer with Canadian Pacific Airlines in Vancouver.

FLT. LIEUT. D. HUGHES (*Associate*), formerly Officer Commanding Transport Command, R.A.F., Luqa, Malta, is now employed at the Air Ministry.

GROUP CAPT. P. H. LEGG (*Associate Fellow*), has been posted from H.Q., M.E.A.F., Cyprus to Headquarters, Flying Training Command at Shinfield Park.

D. LIPTROT (*Associate Fellow*), has been appointed General Manager of Parnall (Yate) Ltd., Bristol.

SQ. LDR. G. K. N. LLOYD (*Associate Fellow*), formerly Senior Helicopter Test Pilot, Commanding Flight Test Section, R.A.F., has been posted to H.Q., M.E.A.F.

L. MALEC (*Associate*), formerly Managing Director of Air Trainers Link Ltd., is now Managing Director of Solartron Radar Simulators Ltd.

FLT. LT. R. C. MORING (*Associate*), formerly Adjutant/O.F.I. to the Army Air Corps in Libya, has been posted to flying duties in Transport Command at R.A.F. Dishforth.

S. OLDFIELD (*Associate Fellow*), formerly Chief Technical Officer with B.O.A.C., has joined the Texas Company of New York as a Consultant (Aviation) and is based in this country.

R. R. SHAW (*Associate Fellow*), formerly with the Department of Civil Aviation, is now Technical Development Controller with Qantas Empire Airways Ltd.

A. W. J. SMITH (*Associate*), has resigned his appointment as an Assistant Quality Engineer with D. Napier and Son Ltd., to take a similar post with Rolls-Royce Ltd., Derby.

C. E. SPEDDING (*Graduate*), formerly with Folland Aircraft Ltd., is now with Saro Structures Ltd., working on the design of commercial structures in light alloy.

J. H. STEVENS (*Associate Fellow*), has recently formed Aero-Enterprises (Boreham Wood) Ltd., to include his business representation for Piaggio and C.S.p.A., as well as his other activities as a Consultant on British and Commonwealth matters for Piaggio.

B. THACKER (*Associate*), formerly a Design Draughtsman at Auster Aircraft Ltd., is now a Design Draughtsman, Atomic Power Division, English Electric Co., Whetstone.

S. WERNICKI (*Associate Fellow*), formerly Personal Assistant to the Chief Engineer (Gas Turbines), D. Napier and Son Ltd., is now Administrative Assistant to the Technical Director.

WING CMDR. J. WILLIAMS (*Associate Fellow*), is now with Marshalls Flying School, Cambridge, as a Technical Assistant.

A. E. WOODWARD-NUTT (*Fellow*), formerly Deputy Director General Aircraft, Research and Development, Ministry of Supply, is now Director General Aircraft General Services.

ELECTIONS

The following is a list of new members and transfers of membership of the Society.

Associate Fellows

James Adam
Alan John Alexander (*from Graduate*)
George Frederick Bates
Robert Glaisby Baxter (*from Graduate*)
Andrew Beveridge
Cecil Harold Bickerdike
Colin Bernard Bolton
William James Bootle (*from Graduate*)
Robert Simpson Brown
Alric Ronald Cawthorne (*from Graduate*)
Reginald Walter Christmas
John Cockshoot
Douglas Henry Cook (*from Student*)
Frederick Creedy (*from Graduate*)
Anthony Richard Ward Denison (*from Graduate*)
Saul Eshel (*from Graduate*)
Donald Eyre (*from Associate*)
Albert David Fowler (*from Graduate*)
Richard Frederick Gash
Leslie James Geering (*from Graduate*)
Hugh Graham Gillespie (*from Graduate*)
Brian John Griffin (*from Graduate*)
John Martin Hare (*from Graduate*)
Robert K. S. Harker
John Henry Hawthorne
Kenneth Herbert Haywood (*from Graduate*)
Kenneth George Heales
Victor Hollingworth (*from Graduate*)
Kenneth James Iddon (*from Graduate*)
Kenneth Elliott Johnson
Edwin John Knight (*from Student*)
Geoffrey Brian Longbottom
John Alexander McTaggart
Peter Alec Marks (*from Graduate*)
Alan Oswald Gawler Mills
Jeffrey Nicholas Montgomery (*from Graduate*)
Malcolm Christison Muir (*from Graduate*)
Henry Edward Nowell
Vernon Roy Parkhouse (*from Graduate*)
Trevor Howard Powell (*from Graduate*)
Frank Milnes Prickett (*from Associate*)
Earle Rhoades (*from Graduate*)
Godfrey Lyall Robertson
Peter Robinson (*from Graduate*)
James Derrick Rutherford
Ernest Merill James Schaffter
James Beat Scott (*from Graduate*)
Edward Graham Seath (*ex-Student*)
George Smith
Thomas Victor Somerville
John Henry Stevens
Edmund Arthur Stockwell
Alexander Symon (*from Associate*)
Samuel George Taylor (*from Associate*)
Reginald Tillyard (*from Associate*)
Grigori Aleksander Tokaty
Robert Charles Travis (*from Graduate*)
Donald Edmund Turner
John Robertson Wedderspoon (*from Graduate*)
Denis Edward Weeding (*from Graduate*)
Peter Westmoreland (*from Graduate*)
Claud Stuart Wilson
Peter Robert Wyke

Associates

Peter John Bardon
Harry Bonney (*from Student*)
Raymond William Bray
Donald Francis Carey
William Ainslie Crane
Philip Samuel Eden
Ernest Edward Evans
John Anthony Louis
Joseph William Herbert Dennis Lovell (*from Student*)
Rafael Luftig
Herbert Roy Mackinnon
Keith Alan Marlow
Stephen Robin Newton
Philip Percy Palmer
Leonard Park
Clifford John Hague Peak
Mukhtar Ahmed Siddiqui
Gerald Arthur Smith
John Chandler Teago
Derrick James Ward
Richard Alan Wigginton

Graduates

Derek Isaac Ainley
John Burpitt Andrews
George Graham Appleby (*from Student*)
Alan Harold Atkinson
Colin Lax Barnfather
William Bell
Martyn Howard Bolus (*from Student*)
Michael Francis Clements
John Robert Cockerill (*from Student*)
Brian Cooper (*from Student*)
John Edwin Dibley (*from Student*)
Robert Clive Dixon
Michael Curtis Eames
Keith Ewing
Anthony John Eyles (*from Student*)
Brian David Gibbs (*from Student*)
Peter Goodwin (*from Student*)
Michael John Goodyer (*from Student*)
Collin Grimes (*from Student*)
Jeremy Frederick Haines (*from Student*)
John Humphrey Hibbert
John Malcolm Holmes-Walker (*from Student*)
Brian Harold Long (*from Student*)
John Anthony McDonagh
Ralph Sydney Noronha (*from Student*)
Brian Pawson (*from Student*)
John Desmond Penrose (*ex-Student*)
Narendra Parshu Ram (*from Student*)
Dilip Kumar Ray (*from Student*)
Walter Bruce Remington (*from Student*)
Michael Robert Rice
John Rudeforth (*from Student*)
Malcolm George Ruscoe-Pond
Ernest John Sandoe
Alan George James Smith (*from Student*)
Thomas Neil Stevenson (*from Student*)
John Ewart Summers
John Malcolm Tagg (*from Student*)
William Joseph Tippett
Malcolm Lewis Toms
Robin George Bennett Webb
Stuart Neville Willmott
Edward Gordon Wright

Students

Ronald Peter Frank Alexander
Robert Frank William Anstee
Pritam Lal Bajaj
Alan George Baker
William Henry Barnes
John Bernard Bentley
John Duncan Berry
Trevor Harry Breckell
Arthur William Cardrick
Peter Derek Chappell
Norman David Charles Clifton
Brian Michael Deluce
Dennis James Gardner
John Edgar Garnett
Andrew John Gidynski
David John Gowers
Herbert Ralph Harrison
Kenneth Roy Harvey
Richard Clive Holliday
Peter George Hopwood
Thomas Jackson Hudson
James William Jordan
John Kelly
Farooq Ali Khan
James Houston McKinnon
John Michael Moten
David Richard Philpott
John Rothwell Reeves
Andrew Brian Scott
David Seth
John Derek Sheffield
Kenneth Simcox
Christopher Peter Smith
John Brander Smith
Roger Bousfield Somerville
Roy Steven Spurgeon
Christopher Lionel Stratford
Edward Martin Strover
Peter Suddaby
Peter John Taylor
Robert Godfrey Taylor
Maung Kyaw Than
Neil Thompson
James Thomson
Derek Edmund Tisdall
Pir Muhammad Toor
John Norman Warren
Richard Geoffrey Williamson
Alfred Harold Wise
David Leslie Wright

Companions

George Bertram Bathurst (*from Student*)
Richard Joseph Wickens (*from Graduate*)

ASTRONAUTICS AND GUIDED FLIGHT SECTION

The Society would welcome to the Astronautics and Guided Flight Section all members working in the Guided Weapons field, Rocket propulsion and other affiliated subjects. No special qualifications are needed and all members interested in this Section may join and a note to the Secretary would insure their registration as a member of this Section. Members of the Section automatically receive particulars of special lectures and discussions.

"MATHEMATICAL TABLES AND OTHER AIDS TO COMPUTATION"

Mr. Harry Polachek, Technical Director of the Applied Mathematics Laboratory of the David Taylor Model Basin, has been appointed Chairman of the Editorial Committee for the quarterly journal *Mathematical Tables and Other Aids to Computation*. All articles for publication should be addressed to Mr. Polachek at Mathematical Tables and Other Aids to Computation, David Taylor Model Basin, Washington 7, D.C.

Papers and Reports Received by the Library

The following I.A.S. Reports, and Papers presented at the Sixth Annual Convention of the Society of Technical Writers and Editors, have been received by the Library:—

I.A.S. Reports

(Presented at the 27th Annual Meeting, New York, 26th-29th January 1959)

Report No.

59-25 Performance of nuclear electric propulsion systems. V. P. Kovacik and D. P. Ross.

59-39 Studies of pilot control during launching and re-entry of space vehicles, utilizing the human centrifuge. C. H. Woodling and C. C. Clark.

59-40 Systems using solar energy for auxiliary space vehicle power. A. E. von Doenhoff and J. M. Hallissy.

59-41 The problem of escape from satellite vehicles. C. V. Carter and W. W. Huff.

59-42 Application of power spectral methods in airplane and missile design. K. R. Thorson and Q. R. Bohne.

59-43 A study of the effects of wind speed, lapse rate, and altitude on the spectrum of atmospheric turbulence at low altitude. R. M. Henry.

59-44 Analysis of atmospheric turbulence spectra obtained from concurrent airplane and tower measurements. U. O. Lappe, *et al.*

59-45 Cosmic ray detection by visual scintillations. H. Yagoda.

59-46 The balloon-borne capsule as a space flight trainer. E. E. Beson.

59-47 Infra-red spectroscopy from balloons and the possibility of some observations on the biosphere. D. M. Gates.

59-48 The strato-laboratory as a systems testing platform. J. R. Smith.

59-49 Special flight testing for the carrier suitability of naval aircraft. R. M. Elder.

59-50 New concept in USAF flight test. H. V. Leonhardt.

59-51 Man-machine integration in space vehicles. G. W. Hoover.

59-52 Implications of space radiations in manned space flight. W. H. Langham.

59-53 Turbopumps for high-energy propellants. A. Ginsburgh, *et al.*

59-54 A look at rocket propulsion for the next 25 years. T. F. Dixon.

59-55 Thrust control of solid propellant rockets. H. W. Ritchey.

59-56 Large deflections of structures subjected to heating and external loads. M. J. Turner, *et al.*

59-57 The equation of energy balance for fluttering systems with some applications in the supersonic régime. J. D. C. Crisp.

59-58 Transonic and supersonic divergence characteristics of low-aspect-ratio wings and controls. D. J. Martin and C. E. Watkins.

59-59 Research studies on a ducted fan equipped with turning vanes. A. W. Gilmore and W. E. Grahame.

59-60 Convertible turbojet engines for VTOL aircraft. M. A. Zipkin, *et al.*

59-61 The space age effect on management (A panel discussion). E. Goetz, *et al.*

59-62 Viscous aerodynamic characteristics in hypersonic rarefied gas flow. R. F. Probstein and N. H. Kemp.

59-63 Viscous hypersonic similitude. W. D. Hayes and R. F. Probstein.

59-64 Propagation of weak disturbances in a gas subject to relaxation effects. F. K. Moore and W. E. Gibson.

59-65 Effectiveness of radiation as a structural cooling technique for hypersonic vehicles. R. A. Anderson and W. A. Brooks.

59-66 Anisotropic composite thermal structures for hypersonic flight. L. Broglio.

59-67 Thermo-elastic behavior of simply-supported sandwich panel under high temperature gradient and edge compression. C-C. Chang and I. K. Ebcioglu.

59-68 Heat conduction in a melting slab. S. J. Citron.

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The First Halford Lecture

Frank Bernard Halford, C.B.E., *Fellow*

1894 - 1955

Frank Bernard Halford

1894-1955

by

JOHN L. P. BRODIE, M.I.Mech.E., F.R.Ae.S.
(Engineering Director, The de Havilland Engine Company)

The news of the sudden death of Mr. Brodie on 23rd March 1959 was received with very great regret just as these pages were going to Press—Editor

The First Halford Lecture, "Frank Bernard Halford, 1894-1955" was given by Mr. J. L. P. Brodie on the 5th February 1959 at the Hatfield Technical College. This was the 33rd Main Lecture of the Society to be given at a Branch Centre and was held under the auspices of the Hatfield Branch.

Mr. R. C. Grinter, A.F.R.Ae.S., Chairman of the Hatfield Branch, opened the proceedings in the unavoidable absence of the President of the Branch, Sir Geoffrey de Havilland, Hon.F.R.Ae.S., by welcoming Sir Arnold Hall, M.A., F.R.S., F.R.Ae.S., President of the Society, the members of the Council of the Society present and the many distinguished Guests. Mr. Grinter said that this was the first main lecture of the Society to be held at the Hatfield Branch and they were very appreciative of that honour and of the subject of their lecture. Before handing over the rest of the proceedings to Sir Arnold Hall he wished also to record the gratitude of the Branch to the Principal of Hatfield Technical College for the use of the Hall and the amenities of the College.

Sir Arnold Hall said that the lecture was not only a Main Lecture of the Society but it was also important as the first of what he hoped would be a distinguished series of lectures in memory of the late Major F. B. Halford.

Major Halford had been one of the outstanding aero-engineers not only of this country but of the world and it was particularly appropriate that the Royal Aeronautical Society should do him honour because he was a distinguished member of the Council for many years and was the President of the Society for 1951-52. He conducted the office as President in a most distinguished way, the more so because, although it was known to few people at the time, he became seriously ill during his year of office; he recovered, but despite the anxiety of the illness he carried on as President and even through the Anglo-American Conference at Brighton, and generally handled things in an efficient way.

Little need be said in this company of Mr. John Brodie who was to tell the story of F. B. Halford, except that there could be no man in the world more suited to deliver the First Halford Lecture. John Brodie had worked with Halford from 1923 until Halford died in 1955; he was now Engineering Director of the de Havilland Engine Company, the Company which Halford himself had led as Chairman and Technical Director for some time.

THE PRIME PURPOSE of this initiative Halford lecture is to speak of the man and his work.

It may seem rather peculiar to preface such a lecture with an obituary but as I wrote one of them with deep feeling in my heart I make no apology for quoting parts of it to start this lecture and later, to expand on those aspects of his rich life which may be of interest.

In *The Aeroplane* of the 29th April 1955 I wrote the following:—

"A great person is lost to the world of aero-engine designers and engineers—Major Frank Bernard Halford—a man who for forty years had his own name and thumb-print on aero-engines which have achieved great fame and honour for him.

"In 1916 he became the 'H' in the famous B.H.P. engine: a young, virile man full of energy and tenacity and, even then, advanced thinking. Through all the years I had known him, and I knew him then, he never lost that immense courage, either in his work or in the severe illness he recovered from two or three years prior to his death.

"Throughout the years he never outstripped his own strength. Each increasing growth in his organisation was taken with assurance and matched to his forward vision. It grew steadily throughout and never to my knowledge suffered a recession.

"Probably his most outstanding characteristic was his amazing forethought as to what the aircraft industry would need in the years ahead. His continuous aim and effort was to design for efficiency, safety, and reliability.

"Surely there is no single man in all the world of aviation who has left his personal signature on aero-engine design so clearly over such a long period!

"In later years he had been stretching out into the new world of supersonic flight and his conceptions had been bold and characteristically simple and robust. He could see where the large thrust engine and the liquid-fuel rocket motor fitted into the pattern.

"I cannot help feeling that whilst we who were near to him have a deep sense of loss, his many friends throughout the aircraft industry, both in this country and abroad, will also regret that such a unique, strong, and brilliant man is lost to us and this world."

Halford learned to fly at Brooklands when he was

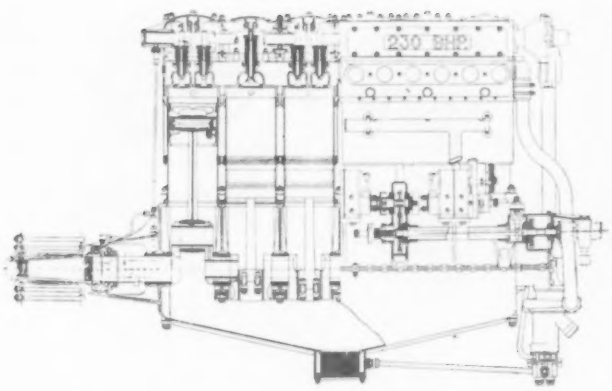


FIGURE 1. 230 B.H.P. aero-engine (exhaust side).

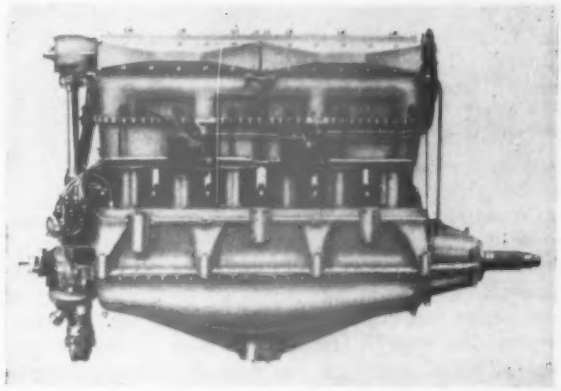


FIGURE 2. Siddeley Puma.

18 years of age in 1913 and within a few months he became an instructor at the Brooklands School of Flying. His Aviator's Certificate was No. 639.

Later he was an Engine Examiner in the Aeronautical Inspection Directorate of the War Office. No doubt this experience at a formative time of his life brought him into touch with the types of engine then in use, mostly of continental design. By the way—did it ever strike you as odd that so many of those early engines had their whole cylinder mass rotating and the crankshaft stationary? What a lot of tough problems designers had to solve then which later practice would seem to show need not have arisen at all!

Early in the First World War he joined the Royal Flying Corps and served in France, initially as a Sergeant. Others have written of his experiences there, but he hardly spoke of them to me.

The Authorities, however, were not inclined to let him continue such a precarious existence and he was re-called to develop the 160 h.p. Beardmore engine with the view to designing a more powerful unit. This he did at Arrol-Johnston in Dumfries and the outcome was the B.H.P. (Beardmore-Halford-Pullinger) engine, a 230 h.p. vertical six-cylinder in-line water-cooled engine embodying cast iron cylinder heads, steel cylinder liners, and sheet steel water jackets.

In the B.H.P., Halford departed from the practice of single large inlet and exhaust valves and used two small exhaust valves and a single large inlet valve per cylinder.

The design was turned over to Siddeley's who changed the cylinder heads and water jackets to aluminium and the title to Puma. They made over 6,000 of them.

I served my apprenticeship with Arrol-Johnston during this period (this in Scotland, as elsewhere, is called "serving your time") and still have a vivid recollection of a very handsome young man, resplendent in uniform with an R.F.C. cross-over tunic and impeccable brown jack boots. He was a Captain in 1916 and set many a female heart fluttering, but the only flutter in which he seemed to be interested related to valve springs.

The B.H.P. and later Puma were installed in the general purpose aircraft D.H.4, designed by Captain Geoffrey de Havilland (now Sir Geoffrey). Thus began a close relationship between two great men: men who knew that the engine had to fit the aeroplane and the aircraft to take all it could from the engine. Most B.H.P.s and Pumas, however, flew in D.H.9s, and many a pilot could, and will, vouch for the excellence of that combination.

A V.12 engine of 500 h.p. using the B.H.P. cylinder assemblies followed, called the Atlantic, but the war ended before the heavy bombers, ordered for the bombing of Berlin, could come into service. Many years later I learned that a good number of Atlantics were installed under tight fitting engine hatches in innocent looking but rather deceptive boats. They were used for certain operations during Prohibition off the American Eastern Sea Board. No doubt their popularity was largely due to the clean pair of heels they could show the American Coastguards when necessity demanded.

Following the development of the B.H.P., the need for more power at altitude was becoming urgent and so, in conjunction with Harry Ricardo (now Sir Harry), Halford set about designing a "supercharged" form of the engine. This was not supercharged in the sense we understand today. There was no gear or exhaust-driven blower. The system employed introduced a stratum of inert exhaust gas and clean air to the crowns

FIGURE 3. D.H.4 with inverted engine.

of the working pistons. The effect of this dilution was to weaken the mixture strength in the cylinder at low altitudes. Increase of altitude brought more of this mixture into use until at heights of between 10,000 ft. and 20,000 ft. it became wholly effective in the working cycle. Confirmed by test thermal indicated efficiencies to 34 per cent were obtained and the fuel consumption fell to 0·465 lb. per b.h.p.hr.

When the engine was initially designed it was apparent that the height above the crankshaft centre line was prohibitive in that it obstructed the pilot's view forward. A solution was found by inverting it and a new design was established. But how to sell it to the powers that were? Here the services of one of the best technical artists of our time, F. Gordon-Crosby, were brought to bear and resulted in the wholly imaginative painting of a D.H.4 shown in Fig. 3. The wonderful forward vision for the front gunner over the engine cowling and through the propeller was apparent. (Constantinesco gun interrupter gear was used.) The painting sold the design. Three of this engine and three of a 12-cylinder type R.H.A. (Ricardo-Halford-Armstrong) were made but the end of the war brought about a cessation of their development.

It should be noted that in this later period of the war Halford was appointed Assistant to A. E. L. Chorlton, who was then in charge of aircraft engine production at the Air Ministry, but he really did not have his heart in the job. No doubt his very good friend Major G. P. Bulman (B.B. to *his* friends) could tell some instructive and amusing stories of that time.

And so by 1918 (41 years ago) Halford already had a considerable string of very fine engine designs to his credit. As some of you will know, the end of the war brought a slump in aviation activity and he joined Ricardo's, spending two-and-a-half years in the U.S.A. disposing of licence agreements for Ricardo patents, notably the turbulent combustion chamber and the slipper piston.

He told of his exaltation in securing an interview with Henry Ford in an effort to interest him in taking up a licence for the slipper piston. His joy was short-lived, however, when Ford asked him how much Ricardo was prepared to pay for its adoption in Ford engines.

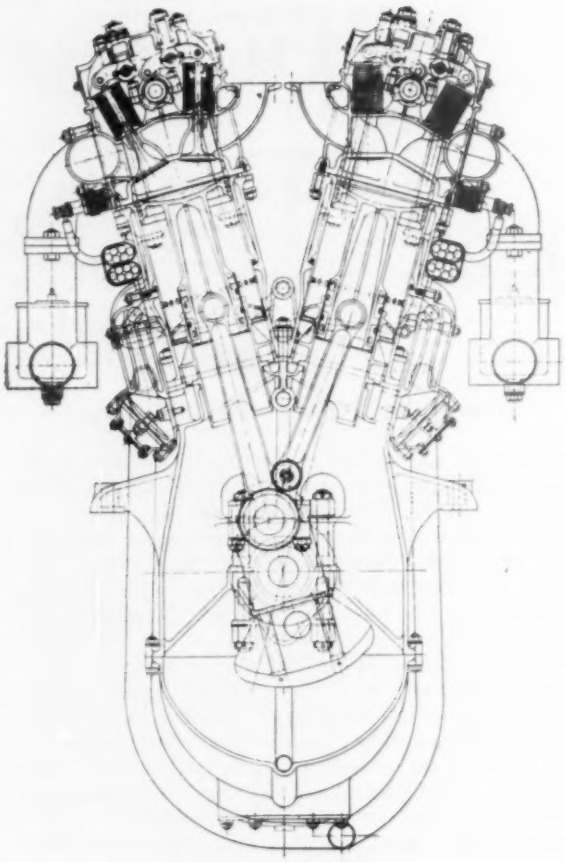


FIGURE 4. R.H.A. engine.

Returning to this country in 1921 he assisted in the design and development of the 500 c.c. Ricardo Triumph single-cylinder motor cycle. This went one step farther than the B.H.P. in its valving arrangements by adopting two exhaust valves and two inlet valves. With this machine Halford set

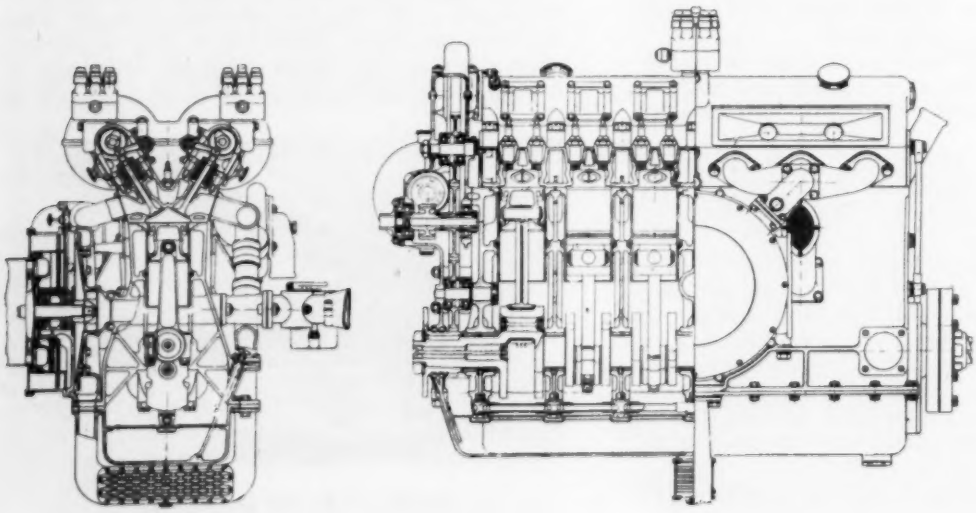


FIGURE 5. 1½ litre racing engine.

up several records at Brooklands, including an hour record of just under 70 miles. He raced it in the T.T. Race in the Isle of Man. Early in the race he got a spot of tar in his eye but still finished eleventh.

In 1923 he severed his connection with Ricardo and struck out on his own—but not quite—because I joined him again then.

In his forward thinking of piston engine design he saw the potentiality of high speeds of rotation in conjunction with small diameter cylinders. This idea was first carried into effect with his design of a racing car engine in 1923 of 1½ litres capacity—six cylinders blown by an exhaust-driven supercharger. The engine revolutions were 6,000 per minute (Fig. 5). The basic design of the supercharger was prepared by the late J. E. Ellor, who, at that time, was employed at Farnborough. Its mechanical detail was discussed in the waiting room at Waterloo Station for lack of a more luxurious venue. The induction system was quite fantastic as an examination of the figure shows. This engine was subsequently raced in a short wheel base Aston Martin chassis, the transmission of which progressively busted as the power of the engine was developed. Although not universally adopted until later in Gipsy engines, and others, this lovely little engine was equipped with forged aluminium pistons and connecting rods. I think this was the first time that forged aluminium was used for such components. It was ultimately re-designed in a considerably lower powered edition, un-blown, and made submersible for use in lifeboats—the first being the Eastbourne boat.

At this juncture the Halford organisation was still two off. It was quite amazing the variations of their initials which appeared on drawings. Just pretending.

In 1924 we entered into a fascinating phase. A vast collection of wartime engines was assembled at the Aircraft Disposal Company of Waddon, Croydon. This Company had purchased practically the whole of the country's stocks which existed at the end of the war. I have heard it estimated at 30,000 engines but perhaps this is an exaggeration. Halford's task was to modernise such of them as held a sales potential.

The 80 h.p. eight-cylinder Vee Renault came first and by redesign of the cylinder head and valve gear it was re-rated at 140 h.p. and called the Airdisco. It was installed in the D.H.51.

About this time de H. was looking around for an engine suitable for a light aeroplane he was designing. It seemed natural that he and Halford should get together on this problem. As a result the Cirrus happened along. It was half an Airdisco, and the first engine was built in a remarkably short time, rated originally at 60 h.p. So again the combination of these two men, who were so geared together, produced a very successful aeroplane—the Moth—and set the foundation for what was to become probably the most widely used series of light aircraft in the world.

FIGURE 6. D.H.51.

FIGURE 7. Cirrus Moth.

Another wartime engine which received Halford's attention at A.D.C. was our old friend the Puma. Quite large quantities were being sold for the equipping of the then new Russian Air Force and it was thought that an up-rated edition would have a market. Thus the Nimbus by Halford out of Puma. The cubic capacity was increased from 18·85 litres to 20·7 litres and the r.p.m. from 1,400 to 1,600, thus producing 335 h.p. for 665 lb. weight. Very commendable at that time. A stiffer crankshaft was needed to suit the higher output and by a remarkable stroke of good fortune it was found that the Atlantic shaft, with slight modifications, was suitable and this was used. Several were installed in D.H.9 aircraft and survey work was carried out by the Aircraft Operating Company in Africa, South America and Australia with these aeroplanes; one of them completed 1½ million miles without mishap.

Other redesigns of war-time engines were undertaken, notably the 300 h.p. Fiat, the Wolseley Viper, and the Sunbeam range named after African tribes, but none of these redesigns achieved fruition.

The Moth, in common with most other aeroplanes,

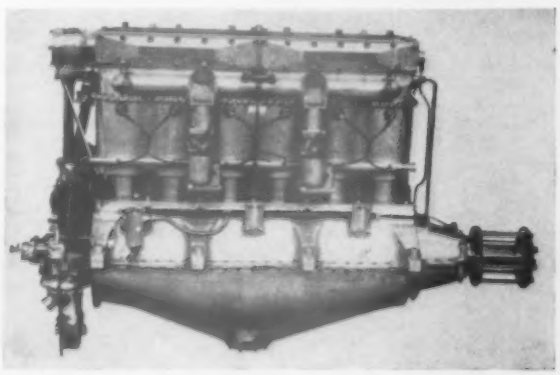


FIGURE 8. The Nimbus.

FIGURE 9. The D.H. Albatross.

was clamouring for more power and to meet the need a Mark II edition of the Cirrus was produced, rated at 80 h.p. This was achieved by the embodiment of a new cylinder head and valve gear, together with a redesign of the induction system.

I should mention that most of this period was interspersed with hectic effort in the installation of the 1½ litre in the Aston Martin chassis and all the many troubles which arose therefrom: also from its successful career at Brooklands.

This saw the end of Halford's association with the Aircraft Disposal Company and we moved offices from Croydon to Victoria.

How difficult it is to speak of a man like Halford without it sounding like a recital of engines, but I am afraid this is inevitable and there is still much more to come.

In Victoria the Gipsy range of engines was born. These have been described elsewhere—*see* Proceedings of the Automobile Division of the Institution of Mechanical Engineers, "The Development of the de Havilland Series of Engines for Light Aircraft," 1950/51, Part II.

It included the Gipsy I, Gipsy II, Gipsy III (this latter the first of the inverted types of Gipsy engines, Gipsy Major, Gipsy Six, Gipsy Ghost 8-cylinder Vee, and Gipsy Twelve (with reversed flow cylinder cooling) and just before the war the beautiful little Gipsy Minor. The list of aircraft into which these engines were installed is legion. One of the loveliest and most efficient was the D.H. Albatross in 1937 equipped with four Gipsy Twelve engines—an all-wooden construction air liner, put into service by Imperial Airways.

Probably the most outstanding aeroplane was the original de Havilland Comet, which won the England to Australia race in 1934 against the best that the world could then produce. It was piloted by Charles Scott and Campbell Black. The two engines were "hotted" up Gipsy Sixes and made to develop 224 h.p. each. They were fitted for the first time in our experience with controllable pitch propellers of rather primitive design. These propellers (Ratier) were in fine pitch for take-off but after a certain forward speed was achieved they automatically changed into coarse pitch and there remained until after landing. An exercise with a bicycle pump restored the fine pitch setting.

In this same period between the wars Halford came to a working arrangement with D. Napier and Son Ltd., and was responsible for the design of the Rapier, the Dagger, and the Sabre series of engines.

The Rapier, a 16-cylinder double crankshaft engine of 8·55 litres capacity, ran at 3,500 r.p.m. and fired pairs of cylinders simultaneously. Rated at 400 h.p. and weighing 720 lb., it was installed in the low wing monoplane D.H.77 designed by de Havilland's as an interceptor fighter. This aircraft never went into production, despite its high performance for such a relatively low power output.

The two most memorable Rapier installations were in the Fairey Sea Fox and the top component, Mercury, of the Mayo composite aircraft. It is probably not generally known that this aircraft (Mercury) flew the Atlantic with a commercial payload for the first time in 1938 and completed its journey from Foynes to New York via Montreal in 22½ hours. Its conception was bold and highly ingenious. It could be thought of as the progenitor of the "stand off" bomb. The war came and the principle of the composite type was dropped, although it deserved further consideration because of its flexibility of operation.

The Fairey Sea Fox had one outstanding rôle to play during the war. If my memory serves me rightly, one acted as gunnery spotter in the British Naval action against the *Graf Spee* in the Battle of the River Plate which resulted in the ultimate destruction of that ship.

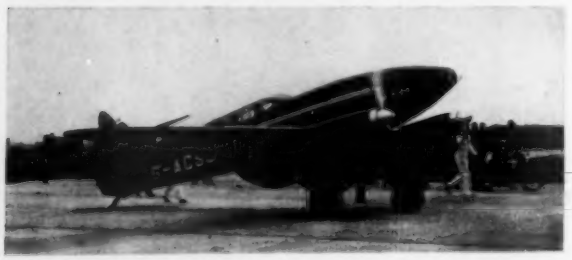


FIGURE 10. The D.H.88 Comet at Mildenhall.

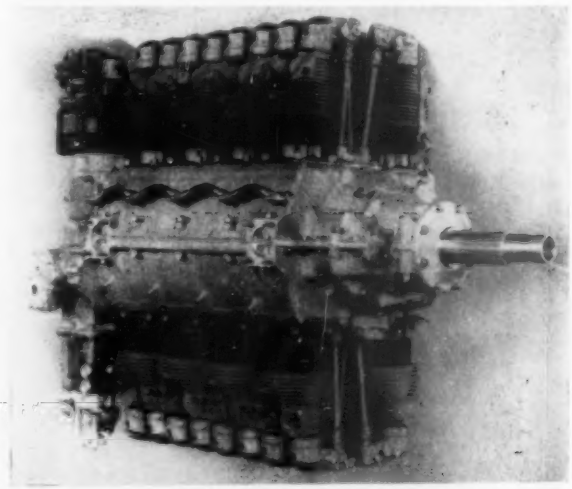
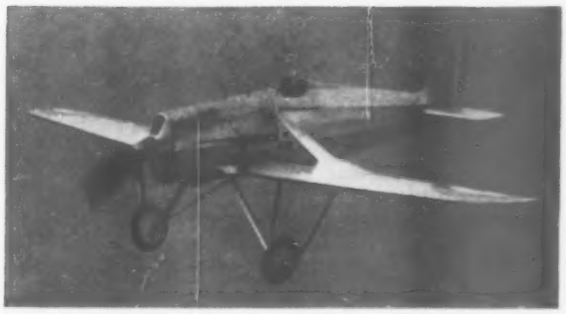


FIGURE 11. The Rapier.



Courtesy of "The Aeroplane."

FIGURE 12. The D.H.77.

The Dagger, a 24-cylinder double crankshaft engine of 16·8 litres capacity, ran at 4,000 r.p.m. developing 1,000 h.p., fired as a 24-cylinder. It was installed in the Hawker Hector and the Handley Page Hereford (a variant of the Hampden) and saw considerable service in the early part of the war. This engine, because of the number of cylinders employed, was fitted with hydraulic self-adjusting tappets in the valve gear thus greatly reducing the time for maintenance in service.

The Sabre was a larger engine of 36·7 litres runing at 3,700 r.p.m., ultimately developed to give 3,100 h.p. It had twenty-four water-cooled cylinders and Halford used single sleeve valves. In its day it was the most powerful piston engine in operation in the world and saw service in the Hawker Typhoon and Tempest.

It will be observed that in those three engines Halford's first conception of small diameter cylinders and high rates of rotation, were again in the forefront of his thinking.

During this period growing pains were being suffered in the offices in Victoria and the move was made to new offices in Golden Square. The staff now numbered seven. Little did the moguls of the tweed industry (who were domiciled there) know of the vital work for aviation which was proceeding in their midst.

About this time several diversionary designs were undertaken, including the Hayes transmission. A fully

Courtesy of "The Aeroplane."

FIGURE 13. The Mayo composite aircraft at Rochester.

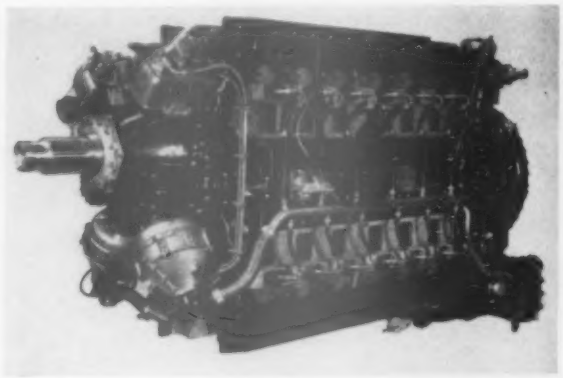


FIGURE 14. Napier Dagger, 24-cylinder air-cooled "H"-type engine. During development the Dagger's output was raised from 610 b.h.p. to 925 b.h.p.

automatic gear with over-drive was manufactured for the 18 h.p. Austin car. Other automobile activities included the redesign, to their advantage, of valve gear in at least two well known British cars.

The need for closer liaison with de Havilland's was becoming pressing and the Company built for Major Halford, in their Stag Lane Works, a suite of offices which was occupied in 1937, the staff then totalling 52. Many of them remain with us today. Perhaps from Fig. 16 some people will recognise themselves as they were then. W. H. Arscott, E. S. Moult, and many others, had joined years before. The outstanding feature of this organisation was the closely knit and happy relationship of each to the other engendered by Halford. It still continues.

Arscott and Moult had transferred much of their effort to Napier's, but the centre of activity was largely maintained at Stag Lane where the whole of the de Havilland output was then located. Engines, aircraft and propellers, all designed, developed, and produced under one roof.

Stag Lane had an aerodrome until 1932 and the close ties between the engine development work and the practical day-to-day business of flying no doubt

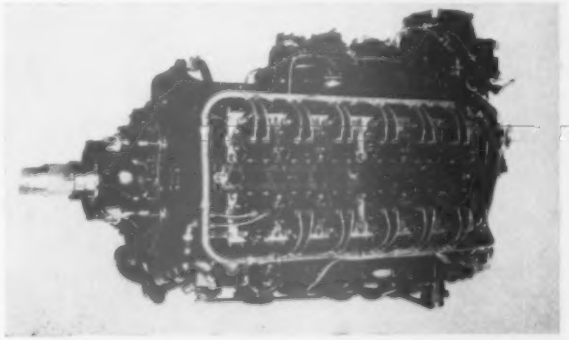


FIGURE 15. Napier Sabre, 24-cylinder sleeve-valve, liquid-cooled, "H"-type piston engine, which powered the Hawker Typhoon and Hawker Tempest. When discontinued after the war the Sabre had reached an output of 4,000 b.h.p. on the test bed.

Courtesy of "The Aeroplane."

FIGURE 16. Stag Lane office.

contributed largely to the overall success of the Company's products.

With the coming of the Second World War engine design work at Edgware fell initially in the doldrums. One rather exciting job undertaken was the installation of the Gipsy Six engine in the belly of a Wellington. It drove an alternator which, in the main, consisted of the motor of a London trolleybus for energising a 50 ft. diameter coil mounted under the fuselage and wings of this aeroplane. It was successful in sweeping the coasts of Britain of magnetic mines. Eventually five of them were transferred to the Middle East and used to keep the Suez Canal open. I have no doubt many pilots of these aircraft could tell of hair-raising adventures arising from the low altitude operation of the machines and their unpredictable detonation of mighty explosions in the flight path.

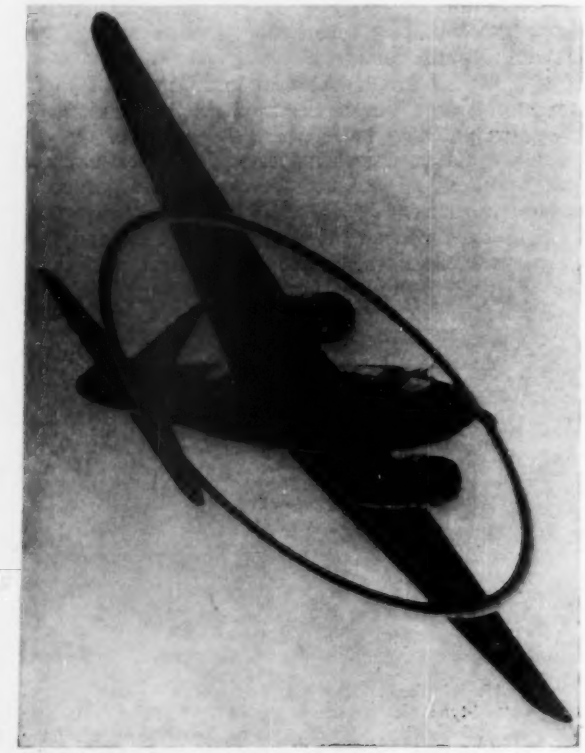


FIGURE 17. The Wellington.

Another task undertaken about this time was the design and development of an auxiliary unit for supplying power to the Shetland Flying Boat.

Work on the upward development of the Dagger and the Sabre proceeded.

It was in 1941 that Halford entered the field of jet propulsion. At the request of Sir Henry Tizard he undertook the design of the original H.1, later Goblin. This engine achieved its rated output of 3,000 lb. thrust within three months of its original running date. It was a measure of the enthusiasm and effort in our wartime factories that from the day the first detail drawing was issued until the first engine was mounted on the test bed, a period of 248 days elapsed; many new problems of design and manufacture were faced and overcome in order that this could be achieved. I quote an extract from a letter received from Major G. P. Bulman, then Director of Engine Development, following a visit to our Experimental Department:

> "Such C.O. as I may have imbibed has not dimmed the immense pleasure and inspiration I got during my visit, fundamentally and potentially one of the most exciting I have ever had."

It may not be generally appreciated that the prototype of the Gloster Meteor, then known as the F.9/40, first flew with these engines, as also did the Lockheed P-80, later named Shooting Star. Another prototype to fly in the U.S.A. was the Curtiss-Wright XF-15C, the forerunner of the combined piston-engine-cum-jet engine conception. Its main use, however, was in the de Havilland aircraft known secretively as the Spider Crab, which eventually became the Vampire. This aeroplane and its variants continue today in manufacture, and the Goblin engine in the Vampire achieved

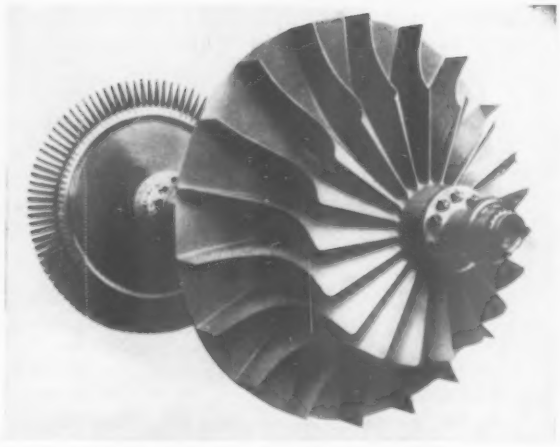


FIGURE 18. The D.H. Goblin impeller.

an enviable reputation for reliability, both in its operational rôle as a fighter and later as a trainer.

It is interesting to note that the experience gained in the Rapier and Dagger, and ultimately the Sabre, with the single-sided impeller in the supercharger, was turned to good account in the compressor of the Goblin.

The Ghost, a larger edition of the Goblin, was designed in 1945. This engine continues in production, being used in the Venom in operation with the Royal Navy and the Royal Air Force. Fitted to a modified Vampire it achieved a World's Altitude Record in 1948 of 59,446 ft. A rather amusing comment on this effort was depicted in a cartoon which showed the author of this lecture cutting John Cunningham's hair, in the hope that he could climb a few feet higher!

During the early part of the war Halford also undertook the design and development of de Havilland propellers. In the relatively short period of two years

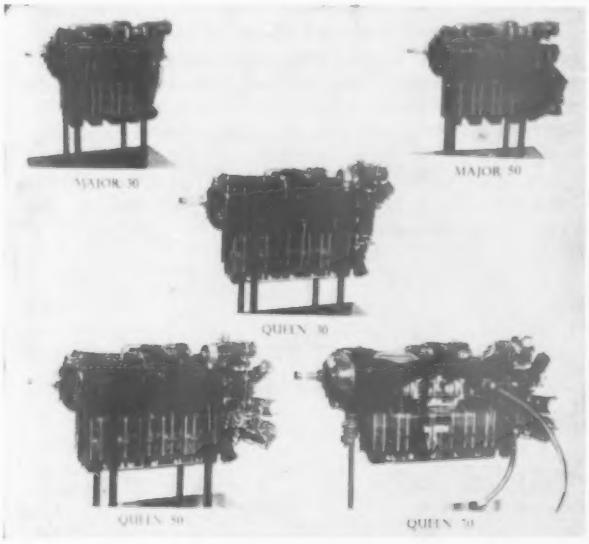
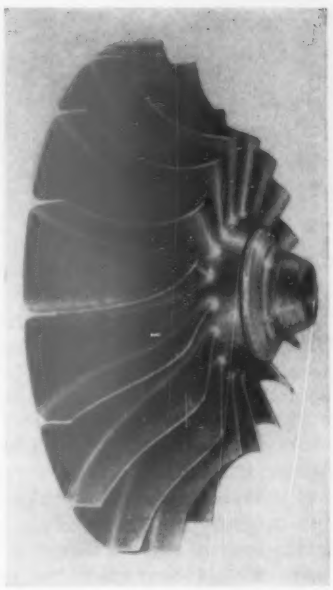


FIGURE 20. Composite of the post-war Gipsy engines.

FIGURE 19. Sabre impeller.



the contra-rotating propellers for the Rolls-Royce Griffon and the Napier Sabre engines were made, and many new projects initiated. This effort expanded so rapidly that in 1943 Halford had to hand the work over to others.

In these brief statements it is impossible to cover adequately the pressures and demands made on Halford and his teams. That he was master of this diverse effort throughout and imposed such force and urgency to every aspect of it, is in itself a tribute to his strength of purpose and sense of responsibility.

The war ended and one would have expected some let-up in effort. We had been working for nearly five years under almost inhuman pressure. In blacked out factories day and night merged, the days of the week had no identity, the hours of working were undefined. The "blitz," to say the least, was unhelpful—spotters on the roof, fire watch rotas, bombs, V1s, V2s. A quiet period was needed, badly needed, but it did not come. The Royal Air Force was being re-equipped. Newer and bigger engines were required and the demands of civil aircraft were beginning to be felt in addition to the military load. In 1943 Halford joined forces with the de Havilland Aircraft Co. Ltd., but, although the staff became de Havilland employees, the work went on much as before.

In 1944 the de Havilland Engine Company Limited was formed with Halford as its Chairman and Technical Director. He had given up his connection with D. Napier and Son in 1943 and he concentrated solely on the new range of de Havilland engines required in the post-war years.

It seems natural that the first of these should be a completely redesigned range of Gipsy engines embodying many features common to each type. The four-cylinder Gipsy Major 30 of 160 h.p. was normally aspirated and had a swept volume of 6·12 litres. This engine was supercharged to be the Gipsy Major 50 of 200 h.p. A new six cylinder, the Gipsyqueen 30, replaced the earlier editions of this type. The Gipsyqueen 50 was a six-cylinder, supercharged engine of 295 h.p., and its more powerful brother, or should I say sister, the Gipsyqueen 70, was identical apart from the fact that its propeller was geared.

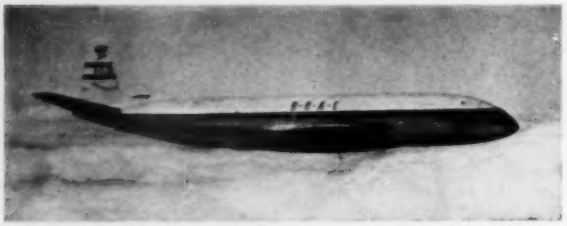


FIGURE 22. The Comet I.

Some of these engines fell by the wayside, but the Gipsyqueen 70 continues to give grand service in the de Havilland Dove and the Handley-Page Marathon, both Brabazon types. The Gipsyqueen 30 is used the world over in the de Havilland Heron. The Major 30 became the Major 215 in the Saunders-Roe Skeeter, and the modernised edition of the pre-war Gipsy Major was installed in the Chipmunk, a new trainer designed and made by de Havilland's (Canada) and also made in England.

In May 1946 Halford addressed a lecture to the Royal Society of Arts on "Jet Propulsion." For use in long distance passenger aircraft he forecast the need for four engines with a take-off thrust of 15,000 lb. each. Fig. 21 shows a hypothetical engine which, in his view, would be required. With an aircraft all-up weight of 190,000 lb. he estimated a cruising speed of 615 m.p.h. at 40,000 ft. and a payload of 15,000 lb. for trans-Atlantic work. On Empire routes the payload could be increased to 22,000 lb. for stages up to 2,200 miles. The cost of such an aircraft he estimated at between £300,000 to £500,000. Was he very far out? except possibly in the cost, and we know that things have doubled in cost since then.

In 1947 a tremendous effort was begun in the "civilisation" of the Ghost engine for the first of the de Havilland Comet jet air liners.

Halford appreciated that an entirely different mentality was necessary in the development of this civil edition of what had been, and was, a military engine—longevity, reliability, safety, all of these were factors of dominating importance. Over 60 per cent of the engine had to be re-tailored to suit the requirements of the aircraft designer. An intensive programme of work was undertaken which included 13,000 hours of bench development and over 5,200 hours of flying in two modified Lancastrian aircraft and prototype Comets.

This activity extended over a period of approximately five years. I think the results obtained proved the common sense of Halford's decision to segregate the development of the civil engine from its military counterpart. He was fortunate in having among his staff many who had considerable pre-war experience in the design, development, and maintenance, of engines in civil aeroplanes, and this fund of experience was used to the full in the Comet Ghost engine.

The sad disasters of 1954 halted its life in this aeroplane for some years. All the world knows how, by the magnificent effort of the Royal Navy, four engines were recovered from one of these aircraft which had crashed in the Mediterranean. It was established from the subsequent examination that they could be completely exonerated from all blame in the accident. As a result of the information gained from this investigation much interesting work was carried out to determine the effect of impact at high velocity on the sea, and of high gyroscopic loadings within the engine, presumed to be due to a severe bunt of the aircraft.

As one of the turbine discs had parted company from its driving shaft and others showed signs of incipient failure, a series of tests was inaugurated in order that the gyroscopic couples could be established which could bring about such a failure. Fig. 23 shows an ingenious rig which was designed and developed by Dr. W. Ker Wilson for the measurement and determination of these forces.

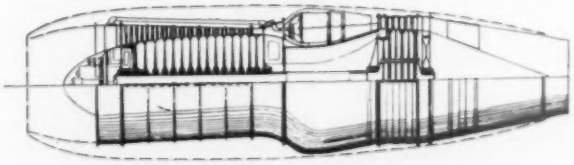
It is not generally known that the Ghost engine had almost achieved 1,000 hrs. between overhauls when these calamities brought a temporary end to their life in the Comet, but it is gratifying to note that they are back in service now in modified editions of the Comet and one of these aircraft, operated by the Royal Canadian Air Force makes us proud to record the fact that it crossed the Atlantic on the 9th of October 1958 in 3 hrs. 36 min. at a speed of 550 m.p.h. The distance covered from Gander to Shannon was about 2,000 miles.

The next long step forward was the conception of propulsion units for aircraft of supersonic performance. Halford saw clearly two definite lines to follow.

1. The design of a large thrust jet engine.
2. The combination of a smaller light-weight jet engine with a controllable high power liquid fuelled rocket.

Both of these schemes he decided were worthy of exploration.

To meet the first case, following an intensive series of design studies, the Gyron engine emerged. Halford had envisaged an engine of comparatively low pressure ratio in which at supersonic speeds the "ram" effect would make a significant contribution to the overall operating pressure ratio. Bearing in mind the need for the smallest frontal area commensurate with the power, he decided to use an axial flow compressor with relatively few stages of blading. This permitted the light-weight construction of the rotative assembly supported by two bearings only, as in the Goblin and Ghost. At the same time this design eliminated what he considered to be a fundamental objection to the



AXIAL JET UNIT

Static thrust (nominal)	12,000 lb. at 800 C. before turbine
Take-off thrust	15,000 lb. at 1,000 C. before turbine
Weight	6,000 lb.
Diameter	5 ft.
Length	17 ft.

FIGURE 21. Schematic drawing of Halford's proposed axial-flow jet unit.

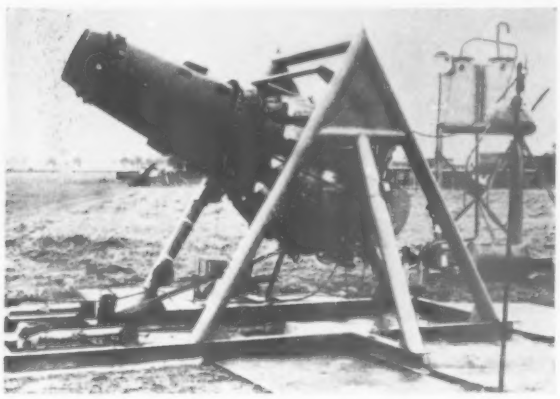


FIGURE 23. Ghost rig.

axial flow engines then current, namely the large number of small compressor blades, both costly to produce and vulnerable in service.

He decided from the beginning to step ahead considerably in dry thrust rating and the engine size was determined to develop 15,000 lb. with an envisaged stretch to 20,000 lb.

There was no immediate official interest in such an engine and so its design and manufacture were embarked upon as a private venture (I would prefer to call this an act of faith) by the Company. It ran for the first time early in January 1953. The design thrust of 15,000 lb. was achieved and by September of the same year it was approved for experimental flight.

The Ministry of Supply placed a contract for its continued development and the manufacture of additional power plants to fulfil this programme. Short and Harland's of Belfast converted a Sperrin aircraft as a flying test bed and flight testing began in September 1955 with engines rated at 15,000 lb. thrust. By this time the engine had been fully approved by official Type Test.

In the meantime bench test and development had continued to thrusts of 20,000 lb. dry and over 23,000 lb. with re-heat. Early in 1956 a second mark of the

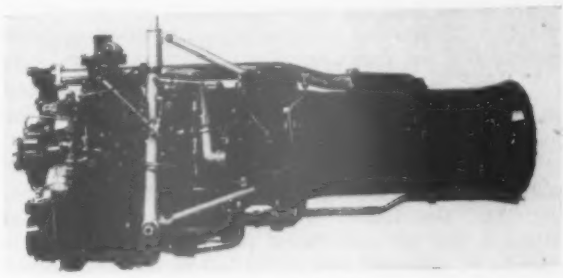


FIGURE 25. Spectre.

engine ran, having an additional stage of blading in the compressor, rated at 25,000 lb. thrust dry. Subsequently engines to this standard have been run at thrusts in excess of 29,000 lb. with re-heat. This thrust converted to 13 tons seems more impressive.

It is unfortunate that no aircraft was forthcoming to use this power plant and it has proceeded in development largely on a private venture basis.

Phase II, based on the Saunders-Roe conception of the mixed power plant for supersonic aircraft, was undertaken, and the design of the de Havilland Spectre rocket engine, operating on hydrogen peroxide with kerosine, was started in 1951. This engine was controllable within the range of 1,000 to 8,000 lb. of thrust. For flight endurance purposes it was essential that a light-weight turbo-jet engine should be used in conjunction with the Spectre and the Gyron Junior was designed approximately two-thirds linear scale of its larger brother. This conception saw fulfilment in the Saunders-Roe S.R.53 which used an Armstrong-Siddeley Viper jet in conjunction with the Spectre.

Halford never saw the Gyron Junior run as it did so about four months after his death. Initial flight experience of both the Spectre rocket and the Gyron Junior was obtained from the adaptation of Canberra aircraft to serve as flying test beds.

The S.R.53 was a research aeroplane and so remains.

The military application of the mixed power plants was embodied in the Saunders-Roe P.177, designed to use the Gyron Junior and the Spectre. A development

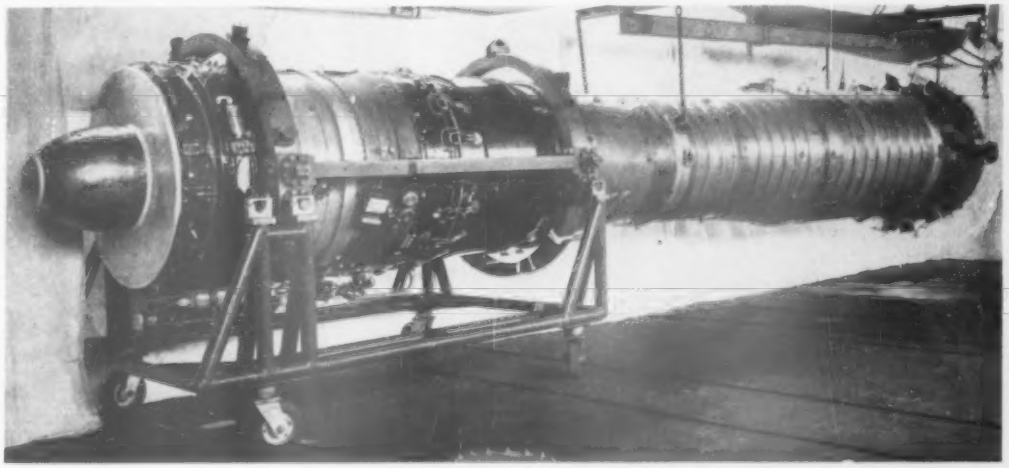


FIGURE 24. Gyron with reheat.

batch of this type was ordered, together with the power plants. Government policy changed, however, and the project was put into abeyance.

Before the Spectre engine, a liquid fuel assisted take-off rocket, the Sprite, was designed to suit the original Comet aircraft but it was found to be unnecessary owing to the excellent take-off performance of the aeroplane with its Ghost turbo-jets. This experience, however, was turned to good account when it was decided that for operational purposes the V-bombers should be equipped with liquid fuel rockets for assisted take-off purposes. Thus the Super-Sprite was designed to meet the needs of the Valiant and a fixed thrust edition of the Spectre for the Vulcan and Victor. In each case these rockets were installed with their own fuel tanks in jettisonable nacelles. Much development work has been completed satisfactorily on the recovery of these nacelles after take-off and their subsequent re-employment.

A further application for a pair of Spectre engines of higher output is being developed for the propulsion of a guided missile which cannot be named.

Two Gyron Junior engines were specified for the Naval Strike Fighter (known today as the "N.A.39") designed by the Blackburn Aircraft Co. Ltd. Although initially of subsonic performance this aircraft and engine hold the potential of considerably higher speed development and to that end the thrust of the engine is being constantly increased and the application of re-heat will unquestionably permit it to meet the advancing need.

This virtually closes Halford's technical life. His experience covered the era bracketted between the Bristol Box Kite and the latest guided missile. What of the future? Possibly nuclear energy for aircraft propulsion? Already Halford has tilled the ground and planted the seed. Who knows what will come forth?

He was not afraid to interchange his experience and knowledge with other engineers, both here and abroad. He wholeheartedly supported the Gas Turbine Collaboration Committee from its inception and in the later years much benefit resulted from the interchange of technical knowledge between the great General Electric Company of America and the de Havilland Engine Company Limited.

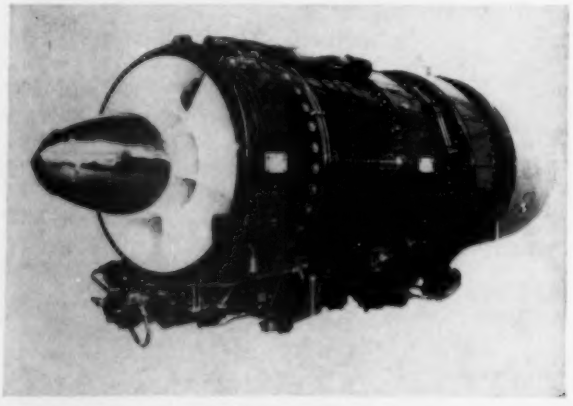


FIGURE 26. Gyron Junior.

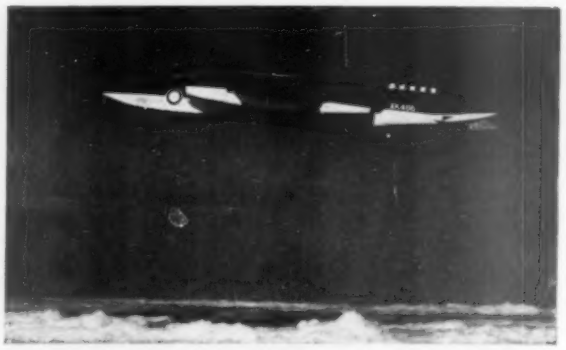


FIGURE 27. The Blackburn N.A.39, two D.H. Gyron Juniors.

It could be said of him without bitterness of any kind, as Kipling wrote:

"and they asked me how I did it, and I
gave 'em the Scripture text,
You keep your light so shining a little in
front o' the next!
They copied all they could follow, but they
couldn't copy my mind,
And I left 'em sweating and stealing a year
and a half behind . . . ."

That he was honoured in his time there is no question. He received the Silver Medal of the Royal Society of Arts, and the Silver Medal of the Royal Aeronautical Society. In 1948 he was made a Commander of the Order of the British Empire and further recognition was given to him in the award in 1950 of the British Gold Medal for achievement in aeronautics. He had been a Fellow of the Royal Aeronautical Society since 1927 and was its President for the year 1951/52. During this period as President he suffered

FIGURE 28. The Halford Laboratory.

and recovered from a very serious illness but he carried out his duties to the Society under great personal distress to the honour of the Society and himself.

There is surely no more heartfelt tribute paid to him than that by his lifetime friend Major G. P. Bulman published in the JOURNAL of the Royal Aeronautical Society in July 1955. In my humbler way I have tried to give you a picture of this truly great man. Space and time, unfortunately, do not permit filling in the many gaps in my narrative.

His memory is perpetuated in several ways. To his old school of Felsted the annual award of a de Havilland Scholarship is made, thus his memory remains green within the walls of that famous school.

The many research facilities which he found essential for the fulfilment of his forward thinking are established within the policies of the de Havilland Company at Hatfield and called the "Halford Laboratory."

This lecture, it is hoped, will initiate future lectures by aeronautical engineers in the field of aircraft propulsion. That Halford set them a hard goal to achieve in creative thinking there can be no doubt.

In Frank Halford it could be said a light shone; sometimes a flicker, sometimes a blaze. In the generations who worked with him and those who will follow, the same light still shines. It will never be quenched. So be it.

ACKNOWLEDGMENTS

I should like to express my gratitude to the following for their help, guidance, and advice in the preparation of this lecture: Captain Sir Geoffrey de Havilland, C.B.E., Major G. P. Bulman, C.B.E., Sir Harry Ricardo, Dr. E. S. Moult, C.B.E., Dr. W. Ker Wilson, and Mr. J. H. Johnston.

VOTE OF THANKS

Major G. P. Bulman, C.B.E., F.R.Ae.S. proposing the vote of thanks to the lecturer, said:— For over 30 years John Brodie served Halford with loyalty, steadfastness, and unquenchable humour, and he had rounded off that long stretch of time by delivering this first Halford Memorial Lecture, covering a veritable cascade of types of engine, rising from that little one-and-a-half litre car engine to the Sabre of 3,000 h.p., and the mighty Gyron of thirteen tons thrust.

But behind all these technical details of Halford's creation, followed by Brodie so carefully, I think we can see, shining through, three characteristics of the man himself. His creative genius; his utter dedication to his work; and his courage. He had no engineering training at all, none of the academic qualifications normally expected. He went straight from Felsted to Brooklands and became a flying instructor. From there he joined the Aeronautical Inspection Department in April 1914, at £2 10s. 0d. a week as an "engine examiner." Curiously enough I do not think he ever flew again as a pilot, and only rarely as a passenger when convenient.

When the First World War broke out he was sent to France, as a Sergeant in the R.F.C. to inspect French aircraft under War Office contract, but came home about January 1915 and was commissioned as Second Lieutenant in the R.F.C., still in the A.I.D., where I first met him in May 1915. About July he was sent back to France to inspect aircraft, and there saw the Hispano Suiza engine and was fired with its promise. He came back and urged the War Office to acquire a licence for its production, for practically nothing. But who was he, a boy of only twenty-one, to engage in affairs of State, and they turned it down—for about a year and then paid a considerable licence fee.

Halford was pretty "browned off" by this snub and straight away, without any direction or authority, took hold of the 120 h.p. Beardmore, being built by Arrol-Johnston, increased its cylinder bore, and raised its power to 160 h.p., which continued for the rest of the War. Not content with that, he conspired with Sir W. Beardmore and Pullinger to let him design the "B.H.P." engine of 200 h.p. He persuaded Geoffrey de Havilland to put the prototype in the prototype D.H.4, ordered by the War Office to take the Beardmore. Frank had 'flu on the day the aircraft was ready to fly, and so I was the first passenger in that classic machine on her second flight with Geoffrey.

As to his devotion and dedication, he was the most devoted man I have ever met. With his immense magnetic and dynamic charm he enjoyed a good life, but his mind was ever busy with his engines, as was obvious sometimes in times of his apparent gaiety. In those First War days, he and Verney and I called ourselves the Three Musketeers, all out for engine progress and damnation to those who would stop it. Halford was the D'Artagnan of the three, the Gascon—and not without a touch of vanity in his make up. Every new conception of his was to be a world beater, and if sometimes it did not come off, he passed on quite undeterred to his next dream of success. He was the essential creative artist, anxious always to "get-on-with-the-next," and a little too apt to leave to his devoted staff the drudgery and sweat of carrying his latest-but-one design into production.

We were great friends, the greatest of my life, for just forty years, notwithstanding that for sixteen years, from 1928 to 1944, while I was in charge of engine development in the Air Ministry and M.A.P. there was always between us the realisation that there must never be any suspicion, or suggestion of suspicion, that he was especially favoured through our friendship. Often with a wry smile he would say to me—"BB, you old blighter, I bet you were more forthcoming in what you told Fedden, or Hives," and so it often was.

Finally, his courage, moral and physical. He was never afraid to challenge the world with his designs and in argument. Never shall I forget that opening cocktail party of the Anglo-American Conference at Brighton when, as President, he took me on one side to tell me that that very morning his doctors had confirmed that he had the most frightening malady—and then went back to receiving his guests. By some miracle, and his own invincible courage, he was .o make a complete recovery within two years.

Halford was always the first to pay tribute to his staff: to join him was to become a permanent member of it. The men I knew with him twenty and thirty years ago are here tonight to honour his memory. He would have wished, I know, that this first lecture should have been devoted more to their collective work than to his alone, but they and all of us have been happy this evening to remember Frank, the man I loved.

And so I most sincerely, and humbly, and very proudly, propose a vote of thanks to John Brodie.

Sir Arnold Hall, closing the meeting, expressed the Society's appreciation of Mr. Brodie's excellent First Halford Lecture and asked the audience to show their appreciation in the usual way.

Air Traffic Control Over The North Atlantic

by

E. W. PIKE

(Deputy Flight Services Manager, British Overseas Airways Corporation)

The 1093rd Lecture to be given before the Society, "Air Traffic Control over the North Atlantic" by Mr. E. W. Pike, Deputy Flight Services Manager, British Overseas Airways, was held on 18th December 1958, at the Institution of Mechanical Engineers, London S.W.1., at 6 p.m. The President, Sir Arnold Hall, M.A., F.R.S., F.R.Ae.S., presided and introduced the lecturer. Mr. Pike had been seconded from the R.A.F. to B.O.A.C. as a specialist navigator in 1942 and in December 1945 joined B.O.A.C. as Deputy Superintendent of Navigation. He was now Deputy Flight Services Manager. During the past eleven years Mr. Pike had been closely associated with international discussions of both I.C.A.O. and I.A.T.A. on various operational subjects. He was Chairman of the I.A.T.A. Flight Technical Group.

BEFORE considering the special case of the North Atlantic, I should like to attempt some clarification of the term "Air Traffic Control" (A.T.C.). It is in fact a service for which I.C.A.O. member states have accepted responsibility dedicated primarily to avoidance of air-to-air collision hazards and secondly, to providing an expeditious traffic flow. When traffic is dense these requirements are somewhat incompatible and, of course, safety considerations are paramount; therefore the traffic flow suffers impediment in some form or other. Traffic Controllers provide service by issuing clearances which are subject to pilot acceptance. Pilots can ask for alternative clearances if they deem those offered unacceptable. Although the A.T.C. service clearly shoulders a large measure of responsibility for avoidance of air-to-air collisions, the ultimate responsibility is vested in the pilot-in-command who is authorised to take any action he considers necessary to maintain safe flight. Pilots violating A.T.C. clearances may subsequently be required by the responsible ground authority to show cause for such action.

In Control Areas pilots are required to maintain communications with the appropriate centre when operating on an I.F.R. (Instrument Flight Rule) Flight Plan. The anomaly of mixed V.F.R. (Visual Flight Rule) and I.F.R. traffic still persists in many areas but not over the North Atlantic, where all civil flights are I.F.R. There seems to be universal recognition now that the principle of relying only on the "see and be seen" rule is no longer completely satisfactory.

Decision as regards the necessity for A.T.C. service in a given area or on a given route rests with the States concerned. The North Atlantic was promulgated as a control area above 2,000 ft. within certain specified boundaries shortly after the end of the last war. Control areas as shown in Fig. 1 are now in force. Each Control Centre accepts responsibility for A.T.C. service in its own area, with the exception that Shannon and Prestwick share responsibility for a common area named Shanwick. Control of a particular flight in this area may rest with either A.T.C. centre, depending on flight routeing, the aerodrome of departure or intended landing and other operational factors. Every clearance has to be co-ordinated by telephone with the other centre.

Traffic flow across the North Atlantic is mainly in an east-west direction, between major cities in North America and Western Europe. Fig. 2 shows how the direct routes between a few of these main originating centres cross over the ocean. Because of this feature, as well as unavoidable navigational variations, pressure pattern flight planning requirements and air/ground communications blackouts, traffic control display techniques and methods were developed originally almost entirely on the basis of vertical separation. Flights are assigned levels which they can follow by means of their common usage of a barometric altimeter at an agreed setting index of 1013·2 millibars. Separation of 1,000 ft. is accepted between opposite direction traffic at levels up to 29,000 ft., with an increase to 2,000 ft. above that figure. Without going very deeply into the adequacy or logic of this practice, there is reason to believe that when the I.C.A.O. Vertical Separation Panel has concluded its work, the technical basis for these values may be questioned.

For eastbound flights odd flight levels at 2,000 ft. intervals are available up to 29,000 ft., then 33,000 ft., 37,000 ft., 41,000 ft., and so on. For westbound flights even flight levels apply up to 28,000 ft., then 31,000 ft., 35,000 ft., 39,000 ft., and so on.

As well as vertical separation criteria there are accepted minimum spacings between aircraft longitudinally and laterally at the same altitude. These are respectively 30 minutes in time and 120 nautical miles, which values were established just after the last war on an empirical basis. Mathematical treatises have been prepared seeking to justify these large figures, but when viewed against the altitude separation accepted they seem somewhat out of balance. However, it can be argued that they have in practice proved safe and any reduction in separation that could not be justified by an improvement in operating practices would mean a theoretically lower margin of safety, invariably an extremely powerful argument when air transport is steadily increasing its overall standard.

The large lateral and longitudinal separation

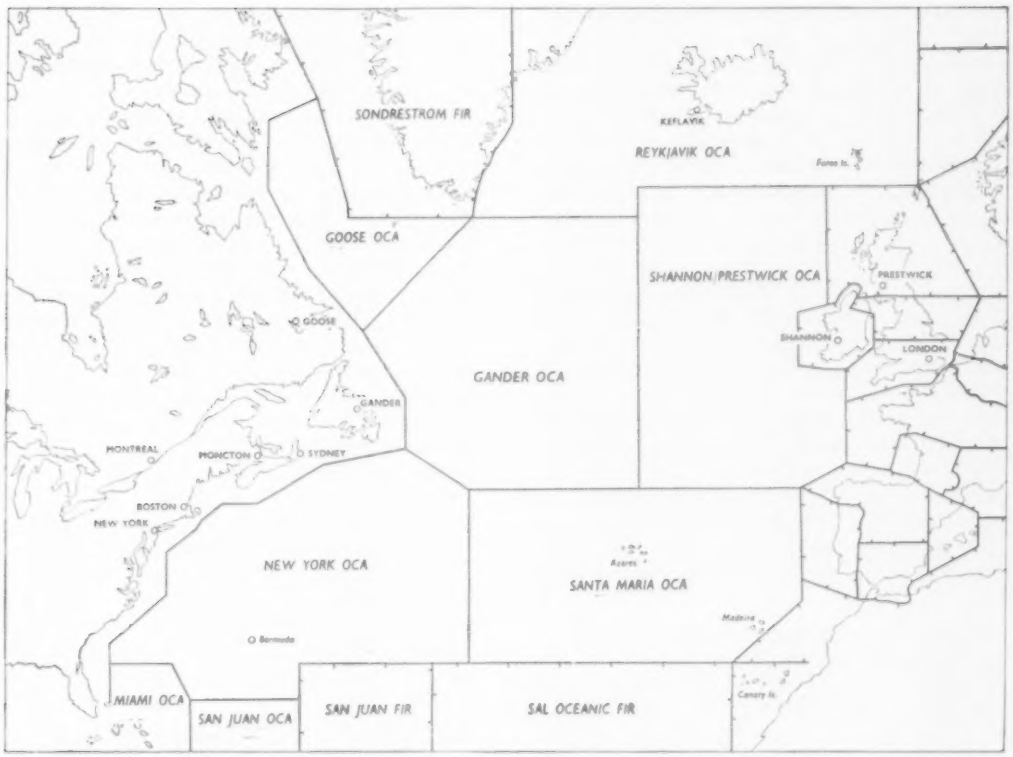


FIGURE 1. Control Areas.

FIGURE 2. Direct routes across the North Atlantic.

criteria are not the only factors detracting from greater use of these methods. A main control boundary between east and west at longitude 30° West will have been noticed. It is natural for traffic controllers to wish to avoid handing over control in a situation where the next Centre may soon be faced with a problem of separation infringement. In fact Centres, by mutual agreement, do safeguard separation for 10° longitude beyond the 30°W boundary for this reason. Varying air speeds and complex routeings frequently make it difficult for a fully occupied controller to visualise precisely when such a situation will arise in the case of horizontal separation. With vertical separation it is always easy to foresee any conflict and, consequently, the layout of control centres has been planned above all to take the fullest advantage of this fact.

At present the main traffic flow in both directions over the North Atlantic is during the hours of darkness, although there are indications that this may change within a few years. There are also peaks during the summer vacation period; roughly between May and October, for passenger traffic. The following table shows how North Atlantic scheduled civil traffic has grown:—

Year	*Number of Flights*
1948	10,771
1949	11,184
1950	10,942
1951	11,037
1952	12,506
1953	14,669
1954	16,336
1955	19,108
1956	22,852
1957	25,492

During the first half of 1958 there was approximately a 27 per cent increase in flights over 1957 (including 935 cargo flights).

The civil flights in 1957 quoted above are a little more than half the total number that took place across the North Atlantic that year, the balance being mainly military traffic.

Permanent air space restrictions on North Atlantic civil traffic are mainly confined to the coastal areas of North America where firing areas, military jet refuelling areas and air defence requirements cause some inconvenience. On the eastern side there are at present few such difficulties, although occasional large scale defence exercises block off huge amounts of air space in a highly disconcerting fashion.

Until comparatively recently all civil aircraft operating across the North Atlantic were piston-engined. Economy was not greatly affected by large changes in altitude, although for reasons of passenger comfort and operating preference altitudes between 14,000 ft. and 22,000 ft. have been more popular in recent years. Signs that insufficient altitudes were available during peak periods were obvious about five years ago. Since then A.T.C. procedural changes and, more recently, improved communications links between Gander and Prestwick Oceanic Control Centres have greatly improved matters. Nevertheless, out of 242 DC Seven Seas flights operated by B.O.A.C. during September 1958, 70 or 28·7 per cent had to accept some variation to flight plan for A.T.C. reasons.

Another factor which has helped to disguise limitations in the A.T.C. system is the increased range of the latest piston-engined aircraft. A few years ago the ocean crossing of roughly 1,800 miles could be planned, only after very careful consideration of forecast winds and terminal and alternate weather. Now that stage lengths of over 3,000 miles are comfortably within range of Super Constellation or DC Seven Seas aircraft, there is less concern from a safety standpoint about altitude restrictions which, at worst, only increase the probability of an *en route* landing. It was not uncommon at one time for an aircraft having planned a direct flight from New York to London to find itself in the early stages denied the optimum altitude due to conflicting traffic, forced to dump a considerable quantity of fuel, due to landing weight limitation, in order to land at Gander, subsequently taking on even more fuel there before completing the flight.

The procedural changes mentioned earlier are worth close examination as they indicate quite plainly the general direction in which further improvements can be effected. All were based on lessons already learned in the control of air traffic over populated land masses and, in fact, follow accepted theories of transportation engineering in general.

A few years ago the only discipline imposed on a North Atlantic flight was the maintenance of an assigned flight level. Pilots could file single heading flight plans based on pressure differentials on each side of the ocean and aircraft drifted happily around the main pressure centres, following roughly the least time track. Others tried to guess in flight changes in the forecast meteorological situation on the basis of their own limited observations and knowledge, altering course at will to try and reduce flight time. As traffic increased, this degree of random movement in the horizontal plane could no longer be tolerated and the first step towards a more orderly system was a decision that a flight plan route, when filed, must be followed as closely as possible unless A.T.C. authorised a departure. Having taken this first disciplinary step it became obvious that position reporting on an unco-ordinated time interval basis involved complex plotting and calculating exercises at A.T.C. Centres (for which virtually no time is available anyhow) if horizontal separation methods were to be extended. It was therefore agreed that flight plans should be prepared and aircraft E.T.A.s and position reports rendered on the basis of times crossing fixed lines of longitude at 10° intervals for east-west movements and 5° of latitude for the much fewer north-south movements. This simplification involved no operational hardship and immediately facilitated clearances based on longitudinal separation.

For the main flow the air space is now divided into blocks defined by longitudes 10°, 20°, 30°, 40° and 50° West and the controller can see by inspection of times entered on the flight progress strips whether the

required 30 minutes separation is provided. Controllers can request that additional position reports be rendered when crossing the intermediate 5° of longitude. Actually for westbound flights only the North American centres at present require these additional reports on a regular basis. A typical layout of an Oceanic A.T.C. Control Centre display board is shown in Fig. 3. Vertical spacing can be seen directly by the position of the flight progress strip in the frame and longitudinal spacing broadly by lateral spacing of the frames.

Unfortunately this very sensible step only brought limited relief because the distance represented by 30 minutes flying time at modern air speeds is much too large when combined with the pilots' preference for a comparatively few altitudes and the airlines' natural desire to arrange their schedules at the same popular times.

Therefore Air Traffic Controllers and others began to consider how the system could be modified to enable greater use of lateral separation. It was immediately obvious that a system of fixed tracks designed to cater for varying weather conditions and laterally spaced according to agreed separation criteria would help enormously. The controller could then use lateral separation as simply and almost as freely as vertical separation, because in both cases his capacity for prediction would be the same. In the Spring of 1958 the

Photograph by William McCallum, Avr.

FIGURE 3. A Control Centre display board.

operators were invited by the Authorities to a meeting in New York to consider acceptance of a fixed track system. The Canadian authorities stated that their acceptance rate in the Gander area at present is only 3 aircraft per 2 hour period per flight level, and forward traffic estimates indicated this was much too low. For reasons that to this author are incomprehensible in that they seem to ignore realities, many major operators refused to accept a fixed track system, even on a trial basis. However, all airlines did agree to the Authorities' alternative proposal (which in actual fact does constitute a fixed track system in another guise). This restricts flight planning to crossing the 10° longitude lines only at whole degrees of latitude. While theoretically this would allow an operator a very large variety of routes, in fact analysis of flight plans filed this summer shows a clear preference for a limited number. Because the current lateral separation criteria is equivalent to 2 degrees of latitude, it is much easier now for a controller to see from inspection of data entered on his board where he can employ this method of separation. Even in the case of converging tracks, if time permits, plotting to check separation laterally is much simpler.

A further means of amelioration was devised by the Oceanic Control Centres following the availability at peak periods of a direct telephone line between Prestwick and Gander. Incidentally, the cost is approximately £35,000 per annum for 10 hours availability daily, which has to be shared between the Canadian and U.K. Governments. After receipt of flight plans and inspection of the meteorological situation a datum line is established separating the main east and west flows and aircraft in either direction are cleared at flight levels normally only available to flights in the opposite direction. This method of injecting more flexibility into separation procedures has been most successful. It was devised by the A.T.C. Centres themselves and is an example of the energetic way in which they have endeavoured to minimise restrictions without impairing the standards internationally agreed as necessary for safe separation.

It will be apparent that with the large criteria in vogue for horizontal separation the controller has the utmost difficulty in authorising changes in flight altitude required for reasons associated with aircraft performance or meteorological conditions. Accordingly considerable use is made of the practice of granting such clearances "subject to maintaining VMC" (visual meteorological conditions). This transfers the full responsibility for collision avoidance during the transition to another flight level to the pilot and it is not surprising that I.F.A.L.P.A. (International Federation of Air Line Pilots' Associations) has strongly objected to the practice. Anti-collision lights now fitted to almost all aircraft have helped during darkness, but with the coming generation of aircraft the use of such a procedure in daylight may have to disappear. This would seriously impair economic operation.

Although so much has been accomplished in keeping the mounting volume of North Atlantic air traffic

moving during peak periods without very serious restrictions, it has involved almost intolerable work pressure on traffic controllers. Experience naturally develops a high degree of skill in handling a rapid input of random information, but even an experienced controller is frequently working for long periods at the full limit of human capacity. Much has been written concerning workload and responsibilities in the cockpit. I feel impelled to draw attention to the responsibilities and loading on a North Atlantic air traffic controller who may be concerned with the safety of 40 aircraft at a time.

Were the operators to continue operating only piston-engined traffic across the North Atlantic there is good reason to believe an intolerable situation would be reached within a few years, assuming the existing rate of traffic increase persists. The impending introduction of jet aircraft is, in my opinion, certain to cause an early crisis in the A.T.C. organisation that can only be averted when the operators collectively appreciate fully the threat to their economy. There are no signs as yet that this stage has been reached, possibly because there is an almost fanatical insistence by some operators that they may be allowed to plan flights in a completely unco-ordinated fashion, and to regard the difficulties facing the A.T.C. authorities as not their immediate concern.

So much for the current situation. One hears assertions that turbine-powered aircraft can fit easily into the current A.T.C. organisation. It is perhaps, therefore, advisable to see whether differences are involved and what they are.

The long range jet aircraft dislikes restriction in altitude and must be operated reasonably near to the optimum section of the performance curve. Operating costs are high and the economic penalty for inefficiency extremely severe. Weight control in any form is of major significance, therefore the fuel uplift, representing nearly half the total weight on a westbound North Atlantic service, is critically important. Fig. 4 shows how small a percentage of the total weight is represented by payload. Consequently fuel requirements and reserves must be very carefully planned. Any likely A.T.C. restriction must be considered during the planning phase and may result in payload reduction, or an additional landing in order to uplift extra fuel. Some idea of the extent of the possible penalty may be gained from quoting figures applicable to the Boeing 707 where percentage losses in range increase very rapidly with large deviations from optimum altitude, roughly 5 per cent less if operated 4,000 ft. higher than optimum and 2 per cent less if operated 4,000 ft. lower than optimum. The penalty for operating from London to New York in 4,000 ft. steps, as against a cruise/climb is about 1,300 lb. or 6 passengers, if it is a critical operation. It may be mentioned here that the economy of a given long range flight is largely settled before it begins. The cost of 5 minutes additional flying in a large jet transport, although high, is only about one fourteenth of the economic penalty suffered if it is necessary to reduce payload by the corresponding weight of fuel involved. view, essential for jet aircraft. In the case of an engine

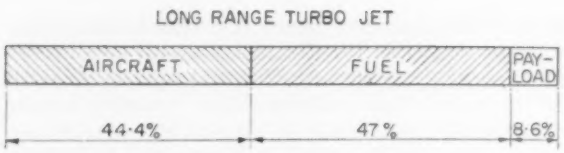


FIGURE 4.

failure, a small pressurisation leak or when encountering turbulence, it would probably be impossible for the pilot to hold a set altitude. With current separation standards and operating limitations there are only two or three acceptable altitudes available in 4,000 ft. increments for westbound flights. If eastbound flights have to be operated on a similar basis the resultant restriction is all too plain, assuming of course that current horizontal separation criteria are maintained.

The next difficulty easy to foresee is conflict with current aircraft. Jets must on occasion climb and descend through their altitudes and, in fact, will share certain altitudes with turbo-prop aircraft. They will be overtaking some current aircraft at speeds greater than air speeds common today. For instance how, one may enquire, will a DC-8 taking-off from Shannon westbound be cleared through the altitudes of piston aircraft already beyond ground radar range?

It may be hoped that for some time the comparatively small number of airline jets can be accommodated, without undue difficulty. This is unlikely however because the upper altitudes are also used by large numbers of military jet aircraft which, up to now, have been granted special block clearances, sometimes for an unspecified number of movements.

Yet another problem is the fact already mentioned that at the closing speeds of jet aircraft reliance on a visual clearance for altitude changes would be quite unrealistic. As I once heard it put by an American pilot "if already on a collision course, looking out of the cockpit would mean you would die all tensed up."

If these rather gloomy prognostications are valid something will have to be done. Before attempting any detailed recommendations, it may be as well to try and specify more clearly the industry's objective and discover how we find ourselves in what may prove to be, for the operators, a highly unsatisfactory position.

Quite clearly the problem in essence concerns transportation and air travel is, after all, only one method. Kipling foresaw some of our current difficulties in his short story "With the Night Mail" written nearly 50 years ago. He propounded the maxim that Transportation is Civilization and certainly, when one learns that a year or so ago the United States was paying 84 billion dollars a year for transportation services, nearly one quarter of the gross national income, such a claim seems justified.

We must have something to learn from the older transportation services on land and on sea. I should be surprised, for example, if anybody who has navigated small boats at night across the shipping lanes, or out of a great river estuary, has any belief whatsoever that any self-controlled collision avoidance system in

aircraft travelling at 500 knots is acceptable. Man is only just taking to the air, and E. S. Calvert in a recent paper has pointed out the virtual impossibility of pilots judging collision risks in the air visually in modern aircraft. The railways years ago realised they must construct their own roads and based safety on planned lateral separation, plus a block signalling system for overtaking traffic; incidentally there is no V.F.R. on the railroads, although a high percentage of accidents thereon are due to visual misjudgments. The mariners have established shipping lanes and collision avoidance rules, although one hears they have sometimes been disposed in recent years to place too much faith on shipborne radar, perhaps a lesson the aviators should not fail to absorb. Motorists are well aware of the necessary action when congestion develops. Dual multi-lane highways, one way routeings, by-pass roads, traffic lights, overpasses and, in the U.S.A. now, even minimum speed limits and traffic segregation on the parkways.

In every case it seems that whenever congestion is reached in any transportation system there must be technological advances in traffic handling, as well as acceptance as necessary by users of an appropriate measure of discipline. There is little doubt that aircraft design advances have now outstripped both development and implementation of the services needed to match striking improvements in aircraft performance; it would certainly seem that this fact is not always realised when orders are placed. The cost of services such as A.T.C., even if borne by governments rather than operators, can hardly be ignored when assessing the real economics of air transportation developments.

Possibly the dynamic growth of this industry in recent years is partly responsible for some of its difficulties. Many airlines are so heavily involved in dealing with immediate industrial, commercial and technical problems that there seems to be little spare effort for planning very far into the future. Governments committed by international agreement to providing ground services are acutely conscious of growing demands on their finances and, particularly where they consider these may be disproportionate, progress in reaching agreements and implementation is inevitably too slow. In the case of the North Atlantic, costs associated with ground services are often incurred because of geography rather than equity and one cannot help feeling some more reasonable distribution of the economic burden is overdue. Although it would involve necessity for defence co-ordination with countries whose territory adjoins the North Atlantic, it would seem eminently logical for I.C.A.O. to establish an International Authority for operating all ground services required for air transportation over this ocean.

The Chicago Convention on International Civil Aviation in 1944 accepted the principle that each state controls absolutely the air space over its own territory. It is agreed also that I.C.A.O. rules apply over the high seas, but the legal situation as regards control of air space is somewhat obscure. An equitable basis for apportioning ground costs would seem to be the number of flights over a period operated by aircraft of each State of Registry using the ground services. An international agency would seem, in theory at least, to be the best instrument for economical operation of these services and to organise a fair distribution of costs.

Another difficulty plaguing traffic controllers is variations in flight planning because of differences in the synoptic picture produced by different meteorological offices. These sometimes cause airlines to choose unnecessarily conflicting routeings and produce variations in elapsed time estimates that a traffic controller often discovers, too late, are based not on air speed differences, but conflicting wind forecasts. While a case can be made for individual forecasting to facilitate economical load planning, there is no doubt whatsoever that it would greatly assist A.T.C. if the estimated elapsed times and routeings on flight plans were all based on a single synoptic chart. This seems a further reason for an international authority.

Two services often blamed for A.T.C. deficiencies on the North Atlantic are communications and navigation aids. While their efficiency does have some bearing on the results achieved, they cannot in themselves be held completely responsible. The first objective should be a proper route structure and associated A.T.C. procedures to move the required volume of traffic in complete safety from air-to-air collision hazard and in a smooth orderly fashion without discrimination. Across the land masses on either side of the North Atlantic air traffic moves along airways fixed in number and size.

There is, to my mind, no really sound reason why a number of carefully chosen fixed routes across the ocean should not be introduced in the near future. Navigation aids such as Dectra can provide accurate track guidance over the whole crossing, making the existing lateral separation standards look grossly exaggerated.

With these modern radio aids longitudinal separation could be greatly reduced also but, given a fixed track system, an even better basis for this method becomes practicable. This would be the use of a separation monitor in the form of airborne equipment (possibly secondary radar) to enable the distance between adjacent aircraft on the same track to be accurately measured in the cockpit. Jet aircraft could then be despatched along the route preferred at a particular time with spacings of probably as little as 20 miles. Procedures for passing traffic in the same direction could easily be devised, subject to A.T.C. approval and, of course, opposite direction traffic would invariably be cleared on a separate non-conflicting track. The number of points at which tracks cross should be reduced to the minimum and separation in the vertical plane at such points provided, when necessary, by A.T.C.

The necessity for taking full advantage of flexibility in routeing to avoid unfavourable winds is often put forward as justifying opposition to fixed tracks. Because of basic forecasting unreliability, minute analysis of upper air charts has never served any real purpose other than to provide compliance with certain

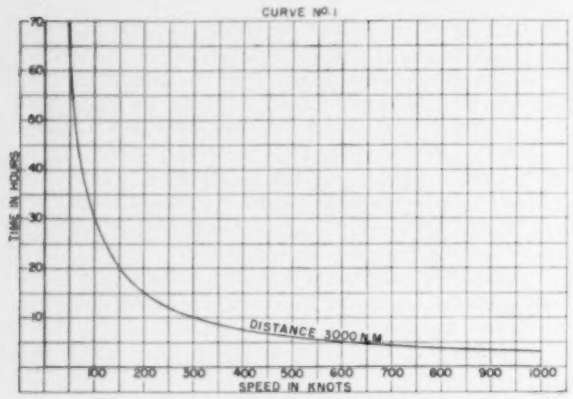


FIGURE 5.

regulations on fuel reserves. With turbo-jet aircraft, increased air speeds markedly reduce wind effect due to much less exposure time, as indicated in Figs. 5 and 6. It will still be desirable to choose optimum routeings, but when the possible errors in the synoptic charts are equated with the much smaller time savings involved, simpler flight planning methods are bound to emerge, thus representing a further reason why a fixed track system should involve no operational disadvantages.

B.O.A.C. has just completed a year's "paper" operations of the Boeing 707-420 between London and New York. This exercise involved preparing a daily flight plan in each direction, based on upper air charts supplied by the Meteorological Office, feeding into recognised entry points on either side of the Atlantic. Figs. 7 and 8 show all the tracks chosen in each direction, together with the percentage of occasions on which they were selected. The general pattern is very similar to that of other Atlantic "paper" exercises the Corporation has conducted with, as one would expect, absence of the more extreme northerly and southerly routes sometimes chosen for aircraft of lower air speeds.

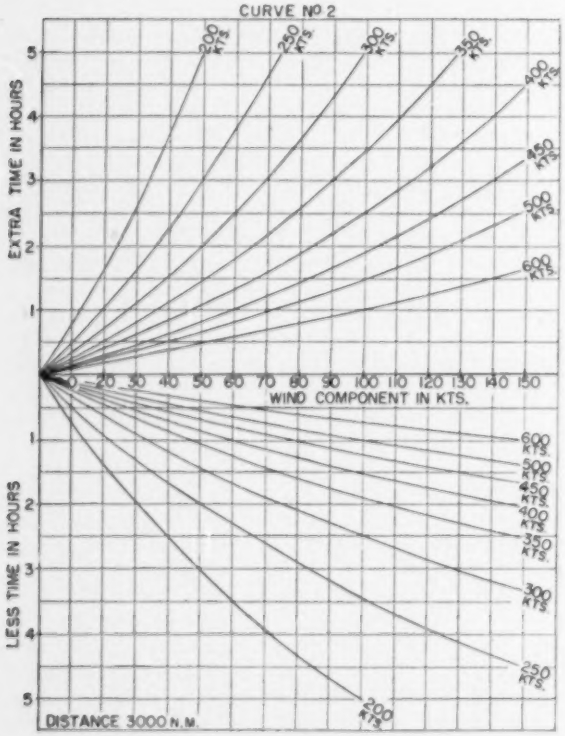


FIGURE 6.

Communications for traffic control purposes must have a very high standard of reliability and enable information to be exchanged between the parties concerned within a time period less than that at which a contingency, after being observed, could be transformed into a hazard. Unreliable or slow communications therefore have a direct bearing on separation standards, particularly in a system where contingencies are frequent. At present nearly all air/ground communications are by radio telephone on frequencies occasionally subject to ionospheric blackouts. The rôle of an orderly route structure as a safeguard in such cases is obvious; in fact an ideal structure[1] would involve no air/ground communications, admittedly a Utopian situation at present.

Once an adequate route structure, accurate and reliable navigation devices and satisfactory communications are all established, there remain problems of data handling and situation display at the Control Centre. Improvements in these respects are already planned and, when provided, the transfer, storage and presentation of data the controller needs will be much more efficient. The next step is to introduce computing equipment in stages to perform routine calculations. The potential benefit from the use of modern techniques can only be exploited when the supply of information has been rationalised. The trained controller will always be needed to deal with the many unpredictable variables involved because, no matter how complex a programme is devised for the electronic computer, sooner or later it would be faced with a problem wherein its repertoire of stock solutions would be found wanting. The precise future roles of the computer and the controller cannot safely be predicted as yet. It does appear that complex A.T.C. problems will best be served for many years by a scientifically devised sharing of duties between machines and men, with final responsibility resting, as at present, firmly with the human controller.

Phrases such as "upper air saturation" and "the vanishing air space" give a misleading impression. There is adequate air space for at least a tenfold increase in North Atlantic traffic without any particularly radical measures. The requirement is to use air space for control purposes much more economically by learning to operate not individual aircraft, but the mass movement of air transport, more efficiently. Changes in services and procedures do not come about very quickly. If we find ourselves inadequately prepared at

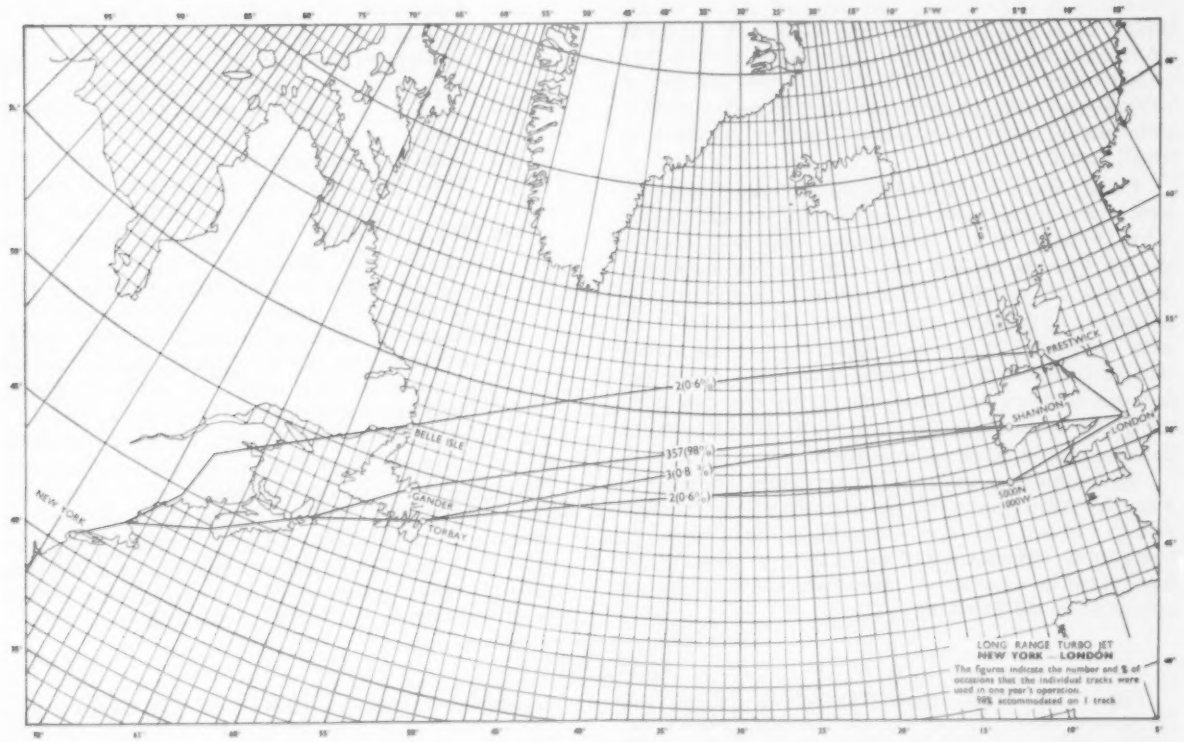


FIGURE 7.

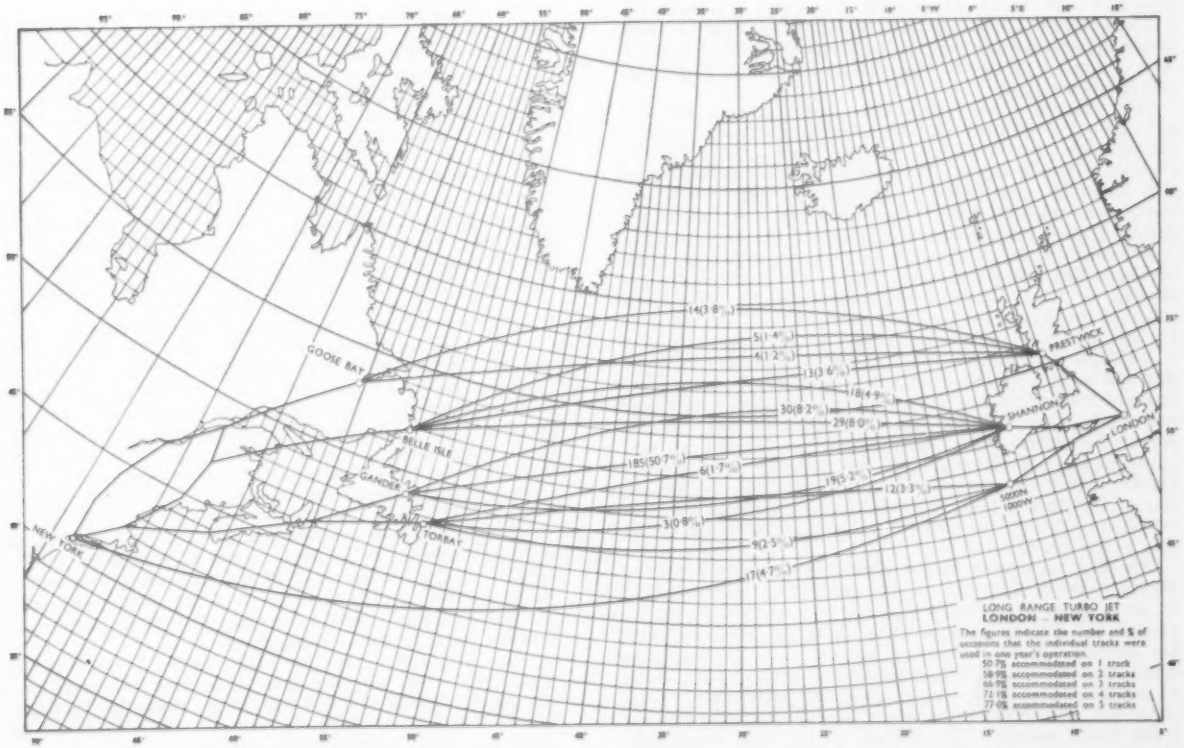


FIGURE 8.

present, it is to be hoped that we shall not be so far behind in A.T.C. practices when supersonic transport aircraft are nearer operation. Perhaps there will then be less objection to channelisation and the principle of allocating separate one-way tracks within such channels, according to speed classification, will be regarded as worth consideration.

Finally there is some advocacy for what I can only term operational anarchy as the means of solving North Atlantic A.T.C. difficulties. This is to control aircraft from the ground only in approach areas and to deal with the collision hazard *en route* on the basis of statistical probability, safeguarding the aircraft only with some kind of airborne proximity warning device that so far has defied inventive scientists. There has been no evidence fortunately that either the operators, the pilots or the controlling authorities are disposed to consider such suggestions seriously.

To summarise, there is already cause for concern over the effectiveness of the current North Atlantic A.T.C. system. If the economic consequences of operational difficulties are as serious as some of us fear, possible courses of immediate remedial action appear to be the following:—

(*a*) Acceptance of a system of selected and co-ordinated tracks.
(*b*) Improved pre-flight co-ordination of flight plans to avoid unnecessary confliction.
(*c*) Use of a common meteorological forecast chart.
(*d*) Provision and general use of better radio navigation aids such as Dectra, to provide accurate track keeping and flight progress data.
(*e*) Highly reliable and rapid air/ground and point-to-point communications.
(*f*) Use of an airborne separation monitor as part of the ground controlled A.T.C. system.
(*g*) Improved information handling and display techniques in A.T.C. Centres, with a gradual move towards automatic computation to handle both static and dynamic flight information.

Although, of course, by no means an essential course of action, there seem to be good reasons why North Atlantic Air Traffic Control, as well as other associated ground services, should be operated by a properly constituted International Authority devoted to promoting the smooth, safe and expeditious flow of the rapidly expanding volume of air traffic between the two main repositories of Western civilisation.

DISCUSSION

Captain V. A. M. Hunt (Director of Control and Navigation, M.T.C.A. *Fellow*): He was delighted that Air Traffic Control had been elevated to the dignity of a Main meeting and they were fortunate in having Mr. Pike to present the paper. Mr. Pike had been studying the application of Air Traffic Control to main line operation for a considerable time. He was much in agreement with practically everything that the Lecturer had said, but there were a number of points which he would like to emphasise and comment upon.

He shared the Lecturer's astonishment at the attitude of a number of the Atlantic operators against introduction of a route system over the Atlantic. Figures A and B showed the sort of problem which faced the controller one night in July 1958. Fig. A showed the plotted position reports for three hours of westbound flights, Fig. B for eastbound flights for the same period. There were 76 flights through that area in a latitude band of about 210 miles and, according to the position reports plotted, at least four aircraft passed directly over each other at the minimum separation of 1,000 ft. and another 16 passed each other at 1,000 ft. separation within a hundred miles; with the navigation facilities at their disposal some of those might have been much closer. He thought they could see from these illustrations that it was not really very easy for the controllers to sort out the pattern of events. At one moment he thought he was going to have to disagree with the Lecturer on this point because Mr. Pike appeared to be overstressing the simplicity of the control task; but later on he did stress the load which was put on the controllers and the problem which they had to try to solve.

He saw no reason why a slightly more formal edition of the "datum line system" should not be introduced at an early date. He thought that now operators were beginning to use jets they would think again about fixed tracks. He entirely agreed with the Lecturer when he said that those enormous block clearances given in the higher levels to military operations were quite impracticable. They could not be allowed to exist any longer. That was already being taken up with the military to see how they could live rather more happily together. Nevertheless, he did not believe that they would get full value from the fixed route system until they had an operational accurate navigational aid working over the Atlantic; this was going to be very important at either end to help the climb-out paths so essential for these operations.

He thought that Dectra, developed in this country by the Decca Navigator Company, looked very promising; it had been running experimentally now across the Atlantic for quite a long time, they had done a lot of experiments themselves with the aid of the Ministry of Supply, and he was delighted that a number of airlines were also testing the practicability of this equipment themselves. The reports they were getting were really most encouraging. He hoped that they would be able to get a number of further large scale experiments going with Dectra so that it could be considered fairly soon for possible international adoption. He believed the time would then come when the administrations concerned with the safety control of aircraft over the Atlantic might well have to take a decision to introduce fixed routes, even if the operators could not come to a unanimous conclusion in favour of such a step.

He shared the Lecturer's view that a separation monitor had a future, while the full-scale collision avoidance indicator probably had not. There was a snag with the separation monitor that it did need co-operation from the other aircraft, so to be effective one had to get everybody to fit both elements. Here he did urge the operators in general to accept a limited objective and not to delay the introduction of the separation monitor by always wanting to have just a little bit more!

If they had had a separation monitor in operation on the night referred to in Figs. A and B, with a range of a hundred miles taking note of aircraft thirty degrees on either side of ahead, alarm bells would have rung on a hundred-and-fifty occasions. And then some people said that the Atlantic was not congested!

The Lecturer did not see much future in "see and be seen" rules. He admitted that the present rules were a bit antiquated but he did not think they could be discarded. They should try to improve them to take account of the many occasions when approach speeds were not a thousand knots but might only be 5-10 knots from abeam.

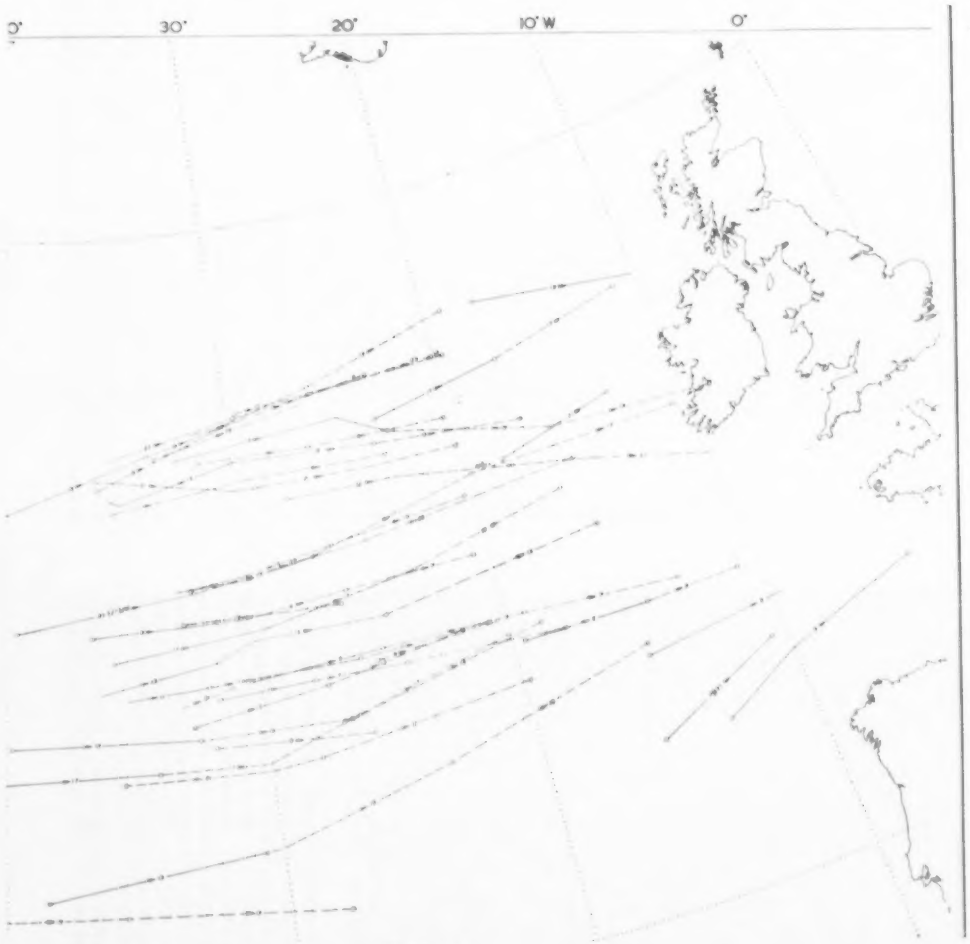


FIGURE B.

FIGURE A.

EASTBOUND →

← WESTBOUND

KEY:

o———o 02.00-03.00
o— — —o 03.00-04.00
o—·—·—o 04.00-05.00

Movements of traffic reported to Shanwick 02.00-05.00 G.M.T. on the night of 16th July 1958.

Coming on to the Air Traffic Control Centres themselves, he looked forward to the introduction of data handling equipment, to ease the load on the controllers and he agreed with the Lecturer that these electronic devices were meant to help the controller and not to displace him. This, to him was a fundamental point in the whole question of control.

Quite a large experimental programme was in being with one of the computer firms for trial on Atlantic problems; in particular for dealing with the flight plan information and calculating estimates and at the various reporting points across the Atlantic, but it would not get involved at this stage anyway in the prediction of incidents. He thought they should remember a point made at the recent Guild of Air Traffic Control Officers' Convention. Computers were really illiterate morons which were useful only when their task was described to them in simple and accurate terms.

The importance of communications facilities had been stressed and then slightly thrown overboard by the Lecturer referring to the apparently casual way the messages at present received were dealt with. Good communications were vital if they were to get down to the more sophisticated approach and attempt to reduce separation standards. Up to date accurate information must be got into the Centre from which the controllers could do their work. He agreed that for control purposes voice communication might die out and thought the trend would be towards automatically coded devices in the aircraft which sent out the message required by the controller, either at regular intervals or when interrogated. Quite a lot of progress on this score was already being made as part of the Decca/Dectra study.

The idea of having a standard Met. chart for the preparation of flight plans was very sound indeed and somehow they must get that sort of thing going. It would not be easy and they might have to go further. They might well have to have some form of flight plan checking office, which would look at those filed plans and let the operators know whether, in fact, they were going to get the clearance they wanted; this would probably need some form of computer. This would be important to help aircraft starting half way, say, from the United Kingdom, to mingle with aircraft that had already started from the Continent.

Aircraft operators in general said that their aircraft must be allowed to "ooze up" or "drift down" to maintain maximum efficiency, but he thought aircraft designers must bear the control problem in mind and try to keep the penalties for incorrect altitude allocation as low as possible. It was sad to think that in the air they had a third dimension which they appeared to be throwing away by a "flick of the wrist," but like everybody else so far he had not been able to see how that could be avoided.

Polar flights had not been mentioned specifically. He did not know whether Mr. Pike had thought about them at all or whether he thought that they could be handled by an extension of the existing plan. Supersonic aircraft had not been mentioned: they were trying to find out what the probable aircraft characteristics were going to be while, in reverse, they were attempting to put to the aircraft designers the sort of things which they thought Control could handle.

The only point on which he really disagreed with the Lecturer was the suggestion that there should be an International North Atlantic Air Traffic Control Organisation. From what knowledge he had of international bodies in peace time they did not seem to be geared up to deal effectively with "real time" problems, nor were they in a position to deal with the domestic projects so jealously guarded by the States involved. Why could they not plan a much more effective North Atlantic A.T.C. system which could still be operated by national teams?

Mr. Pike: As regards see-and-be-seen, what he wrote and what he intended to say was that complete reliance on see-and-be-seen was unwise. He would be the last to disagree that something should be done to improve visual conspicuity. He doubted whether much could be done by amending rules, as pilots did not act by rules in emergency. He thought anything that could be done to improve aircraft conspicuity by lights or any other means was something that ought to be done. Design of windscreens, keeping the pilots alert, attracting their attention, they should do everything they could in those respects.

As regards use of the third dimension, he was sorry if he gave any impression that vertical separation would disappear. He considered that it would still play a major part but he would like to see the other methods of separation elevated at least to the same stage of usefulness.

Most of the so-called Polar flights went nowhere near the Pole, and so far as he was concerned they should be subject to an orderly route structure as soon as the volume of traffic was sufficient to merit this step. He still believed that Atlantic Air Traffic Control would be much better if operated by one Authority. He saw no reason why an International Authority should not be efficient; if it were run by Captain Hunt's department he was sure it would be. But above all this the Authority would be able (he hoped) to ease the perplexing and vexatious problems that arose in the Shanwick area and elsewhere.

Lt. Colonel R. L. Crawford (U.S.A.F.): He would like to make a few remarks on their position in the Air Traffic Control picture. At South Ruislip they had a Control Centre which maintained operational control over all Military Air Transport traffic in the UK-Continent-and North Atlantic area to the extent of some 600 flights per month. As they were primarily interested in the shortest time route, the Centre at South Ruislip performed the function of centralised flight planning for all M.A.T.S. stations in the U.K. and on the Continent. Over the North Atlantic routes they had some 45 tracks, however about five were utilised 80 per cent of the time. With the ideal track a flight plan was drawn up and transmitted on Mufax equipment to the pertinent Military Air Transport station on the Continent or in the U.K. As they were interested in the shortest time route and as their Centre did all M.A.T.S. flight planning, it was quite possible that a large volume of military transport traffic would be utilising just one track for a considerable period of time. Other civil agencies would undoubtedly have tracks closely adjacent thereto. Because of radio propagation, limited navigation aids, and lack of air discipline (such as maintaining filed True Air Speed), it was felt that the present longitudinal and lateral separation was the minimum allowable at the present time. Particularly in the areas south of Greenland it was quite common to have lengthy periods of radio blackout. With changes in ground speed due to unforecast winds and/or air discipline problems, it was understandable why minimums should not be altered.

With better communication it was felt that more extensive and longer range radar control, particularly over entry and exit points, would be a prerequisite before reducing flight control minimums. For instance, many of their usable tracks converged into several entry points on flights into Newfoundland and Labrador. Because of similar limited entry points for other agencies, it was obvious that converging tracks needed close traffic control surveillance for proper lateral clearance.

The Military Transport Service was presently operating turbo-prop aircraft. Under such operation it was mandatory that they flew a step type curve to reach their final altitude. Freedom of vertical climb to initial step altitude was quite important and could be effected most adequately with good radar coverage. Going direct to final altitude would decrease the payload up to 40 per cent in certain instances. With this step operation it was obvious that communications should be adequate and that climb clearances be granted expeditiously when desired. Under the present control with existing longitudinal, vertical and

lateral limits, this was not always possible, and would become more of a problem with increased jet activity.

Mr. Pike: He knew better than to disagree with the U.S. Air Force if they wanted to continue using Stephenville on occasions! He presumed that Col. Crawford was speaking largely on behalf of M.A.T.S.

Captain Woodman (Flight Captain, B.O.A.C.): In general, he agreed with the lecturer whole-heartedly, but for his statement on communications, with which Colonel Crawford was also at variance. He thought one of the main reasons why they could not reduce separation was the inadequacy of communications, especially in the northern latitudes of the North Atlantic that were referred to, where controllers were more liable to be faced with critical converging traffic. This comment, although implying slight disagreement with the lecturer in his views on communications, did back up his views on track discipline with which he was in full accord.

As a pilot flying the North Atlantic, he thought it was true to say that they, as well as the Air Traffic Controllers, had done a considerable amount to keep the problem in check over the past year or two. The lecturer did say that things might have been far worse had the Controllers not got together and through the use of their trans-Atlantic telephone link enabled more effective use to be made of the air space, thus easing their lot and the lot of the pilots in that fewer clearance requests were denied them. However, he thought the pilots played their part as well by accepting seeing-and-be-seen clearances. This was the crux of the immediate problem facing them in the next year or two, and he believed that individual pilots would become more and more reluctant to accept this type of seeing-and-be-seen clearance. The reasons for this were all too well known to be gone into there.

There was a remark made on the subject of pilot's obeying rules. A number of those present tonight were in Monte Carlo in September and might have seen him in the Casino enjoying the roulette. In spite of this he had no wish to play the Russian variety, and not obeying rules now meant just about that. This could only stress the importance of the work that Mr. Pike was doing in the international field to focus attention on the vital problems facing Air Traffic Control on the North Atlantic. He fully supported the seriousness with which Captain Hunt and his department were tackling this problem, which to those in the aeroplane were very real.

A. C. Campbell-Orde (Consultant, *Fellow*): Mr. Pike's lecture inevitably referred mostly to scheduled operations, and, he thought, touched rather lightly on the subtle effects of the crude features of the present position in planning a scheduled operation. He hoped that Mr. Pike could perhaps have said a little bit more about that because that was where the economy of the scheduled airline operation felt it most, since they had to insure themselves against all those variables in their present planning.

Secondly the expansion of airline operation together with a very large increase of operating speed, the effect of which became even more obvious if they moved into the supersonic range of speed. Whatever the international difficulties they must have a much more centralised means of controlling air traffic. He thought that the main lesson which Mr. Pike's lecture had taught them—and it came out very clearly was that they must think more of the other fellow than they had in the past.

Mr. Pike: In designing aircraft, selling aircraft and operating aircraft the question of fuel reserves cropped up perpetually. But he thought they needed to get this issue into perspective. Fuel reserves were a form of safety insurance from the point of view of the pilot in the first place and to provide regularity in the second place. They were the only protection that pilots could demand against service inaccuracies. If one were able to operate always according to plan one did not require reserves, or only very small reserves; but as protection against inefficiencies at the aerodrome, or in the Air Traffic Control services or against Met. forecasting errors and so on, one must have this form of insurance.

They were inclined to think of holding as something inevitable but he submitted that it was not, for in a sufficiently well planned operation there would only be holding in emergencies. They must carry the idea of planned operations right the way through, and be able to take off in all conditions, fly according to plan and land regardless of weather. They must learn how to land not only individual aircraft, but flocks of them under full control in all weather conditions. They were in the mass air transportation business and must operate aircraft efficiently according to their classification. Here again he thought they could learn from other forms of transport, and foresee supersonic aircraft tracks, subsonic tracks, and similar set tracks for other aircraft, each proceeding on their lawful occasions to the destination to which they were bound. This had got to be, otherwise they would be in the position that they were with road transport in this country because of failure to plan sufficiently far ahead.

Strictly from a traffic control point of view, speed mattered less than speed differential. The thing that plagued the traffic controller was speed differentials. Soon one would have jet aircraft overhauling conventional aircraft at speeds greater than those current today. This presented the controller with a particularly difficult problem to resolve; computers would help but were not the complete answer. The controller had to have a proper display of the dynamic situation with the air traffic as a whole moving in a disciplined and rational manner.

Lt. Col. Emerson (Division of Flight Control, U.S.A.F.): He wished to offer a few words about altitude reservations. An altitude reservation was only a means of getting an aeroplane or a group of aeroplanes from point *A* to point *B*, and, contrary to popular belief, was not an expensive use of air space. It might have been in the past but any disregard for air space ended when civil aircraft began jet operations. It was true that in the past the military had almost sole use of the upper air space *i.e.* above 25,000 ft.

In the United States the military had had sole use of the upper air space until recently. In the spring of 1958 the controlling agencies instituted two or three positive control air spaces across the United States. That was the end of the military monopoly of the upper air space. They became aware that the civil air operations were sharing the upper air space. Until then, with the military being the only ones concerned, altitude reservations had been made that utilised a huge block of air space; at least one hour in front of the lead aircraft and one hour behind the last aircraft. The Strategic Air Command realised they could no longer do this or allow any disregard for the air space an aircraft did not essentially need. So the criteria for altitude reservations was changed.

He would like to mention a few points which had changed, some in the past few months. The controlling agencies requested that some means be devised so that they could roll up the reservation behind the last aircraft. That request was taken to headquarters Strategic Air Command and staffed. Now they had the requirement for position reporting where in the past it was denied for security reasons. This accommodated moving the reservation laterally if the occasion warranted and provided for rolling up the air space behind the aircraft. By breaking radio silence the controllers could raise or lower the reservation to accommodate other traffic. So today the altitude reservation the Strategic Air Command was using was in reality just a little greater air space than the space utilised by one aircraft. Before an altitude reservation was requested there must be a minimum of three aircraft in the formation. Therefore they were flying three or more aircraft in the same block of air space which one aircraft would require. And they had to cancel the reservation and file individual clearance if it became apparent, and far enough in advance, that less than three aircraft would occupy the reservation.

Another factor he wished to consider was refuelling. This factor was one of the prime reasons that an altitude reservation was necessary. To refuel they must descend the jet from jet altitude to conventional altitudes, complete the refuelling at conventional altitudes and bring it up again to jet altitude. Moving a jet through the conventional altitudes was a difficult phase of control, as Mr. Pike had mentioned. Their jets were operating at the limits of their range so they had to be able to gain clearance quickly for descent and climb for refuelling.

He was very interested in the separation device that had been mentioned. He thought that would contribute greatly to controlling the air space over the Atlantic and in other parts of the world.

He was curious as to how an international agency would work. He did not see how such an agency could effect the required co-ordination with the lateral agencies, the present international agency did not. To be more specific: he believed that at the present time there was a decided lack of co-ordination between Spanish control, French control, Prestwick and Gander.

He did not quite agree that communications were no problem. He would like to suggest that communications and navigation were quite synonymous; to have absolute control of an air space one must have immediate communications, in order to have complete control of an air space one must have precise navigation. One without the other made control difficult. He felt that to have absolute control over an air space one must be able to pin-point the aircraft and have immediate communication between the air crew and the controlling agency.

He wished to offer a suggestion for controlling the traffic over the North Atlantic, and that was to have positive controlled air space or airways. The routes should be great circle or as near great circle as possible. The size would depend upon the ability to do precise navigation and the capability of communications.

Mr. Pike: He might have been misunderstood on this communications question. In his paper he had put forward entirely reliable and rapid air/ground and point-to-point communications as one of the major requirements. What he disagreed with was any assertion that communications on their own would effect any significant improvement in the A.T.C. situation.

T.C.A. had made an investigation at Gander a year or so ago into the receipt of communications intelligence from aircraft, its handling and the effect on traffic control. In fact they came to the conclusion it had little or no effect and if all the communications had come through rapidly they would have generated more concern, led to more restrictions and the controllers would have been even more worried than they were without the information. He was perhaps looking a little far ahead, but he was sure Col. Emerson occasionally drove one of those massive modern American motor cars on the Parkways of his country where the only communication he had with the turnpike authority was about every 60 or 80 miles when he had to put 25 cents into a slot meter; there were no special communication rules; there were the lanes (*i.e.* the airways he referred to were there), one way traffic and he proceeded on his lawful occasions without let or hindrance. When they came to supersonic aircraft, did they really think there would be reporting of position every set ten degrees of longitude? He thought that when one had these supersonic missiles with their associated blow torches one would be virtually in a guided missile and the whole operation be taken under strict control and landed automatically. He did not want to give the impression that communications were unimportant, but he thought the speed and reliability needed were directly related to the control cycle.

The International Agency—he submitted that one of its problems would be to fill in the gaps mentioned. The trouble at the moment was that a State could not always see why something had to be provided out of its own finances to solve a traffic problem which might entirely concern only aircraft registered in other countries. It was of course a fact that the United States operated altogether something like 80 per cent of the aircraft at present flying across the North Atlantic. But the part their country played directly in the control of the Air Traffic across the Atlantic was a singularly small one; as a matter of fact Iceland and Ireland played a much larger part in the actual control of Atlantic aircraft. His suggestion was that air traffic services should be all organised on an International basis mainly for the benefit of all the users, with proper co-ordination with the local control centres into which aircraft must enter when they got into the Continental limits on either side of the ocean. The suggestion of airways was exactly what he meant by a co-ordinated track system, these tracks would have width, in fact finite dimensions, governed by navigational accuracy.

They had learned to their cost many years ago that one could not have traffic control over land without airways and nobody had yet succeeded in convincing him that there was any other method whereby a large volume of traffic could be controlled safely and with reasonable expeditiousness.

Sir Frederick Tymms (*Fellow*): One of the few controversial points raised by this lecture had been the proposal for an international agency and he was rather gratified to find so much attention given to that by other speakers. The lecturer declared his belief that an international agency for the operation of air traffic control and air navigation aids over the North Atlantic was necessary for the efficient control of air traffic; Captain Hunt had disagreed with him. Whether it was necessary or not he was not going to express an opinion, but he thought it might be interesting to look back at what had already happened in this connection. At the Chicago conference in 1944 and I.C.A.O. meetings immediately following it, there was expressed not only a belief in the necessity but the demand that there should be a world-wide international agency established for the financing and operating of all ground services—more particularly air traffic control, communications and meteorology. That problem was worked on for three or four years. Gradually it was dropped for the very good reason that contrary to expectation, individual countries were providing at least enough to get along with. There was a great reluctance by States generally to participate in, and contribute to, an international agency. On the other side every country was jealous of its sovereignty and determined to do everything in its own territory by itself—just as every country decided it must have its own airline. At the same time prestige was at stake—the countries thought they would lose prestige if they did not provide what was wanted. There was another reason why it was not so necessary as had originally been thought. In the meantime, international agencies, like International Aeradio, set up by the operators, had come along and provided a good deal of what was wanted, where it could not be provided by the countries concerned. But it was still done on a national basis, that was to say International Aeradio contracted with a State to operate its particular share, so that the services were all still nationally provided and controlled.

The next phase was the necessity pressed on I.C.A.O. of redistributing the economic burden, which Mr. Pike had referred to. I.C.A.O. spent five good years wrestling with that problem. Although it was a world-wide problem the North Atlantic routes were taken as the basis for the study because of their importance and perhaps because there it pressed hardest on the countries that counted most. The problem simplified was that three, four or five countries were providing the organisation; twenty or thirty were benefiting by it. One side of the problem was to equate Shannon, for example, with Gander and the meteorological services of the Canadian North. That was difficult enough, if one considered how many of such things had to be integrated and equated. Then one had to

work out how much relatively each of the airlines, or the countries whose airlines operated across the Atlantic were benefiting. It was almost an insoluable problem.

That was the second phase in this international treatment of the problem. It had not been solved. If in fact technical considerations, as he noted a number of speakers believed, forced the establishment of an international organisation for reasons of safety and efficiency a new factor was introduced in the international arguments which went on, and this might be effective. But in the light of what he had said, he thought that to say that to bring an international agency into being would be a major international operation, was an understatement. An enormous concentrated effort would be required.

He would like to add one other thing. It had been agreed that an accurate system of navigation over the North Atlantic was required for proper air traffic control. Here was another international problem—the battle of the standards! In the middle ages men fought battles around the standard: it was surprising to know that they were still fighting battles around the standard. The principal protagonists were out to capture the I.C.A.O. standard. Why? Because economic benefits accrued from it. There was a danger in that. The international standardisation of one type of technical equipment to the exclusion of all others and under economic pressure could kill progress.

Mr. Pike: He would never presume to raise any issues with Sir Frederick Tymms on International Affairs. However, he thought Sir Frederick would confirm that the original responsibility of I.C.A.O. was for civil aircraft only, military aircraft being considered outside the Convention of 1944. They were now in a situation where military aircraft on the North Atlantic represented about half the total traffic. Certainly Captain Woodman would be just as annoyed if the collision he might be nearly involved in was with a military instead of a civil aircraft. It seemed to him that an International Authority would be capable of looking after both military and civil interests; in other words it would have a military as well as a civil component so far as its direction and responsibilities would be concerned.

Dr. K. G. Bergin (Chief Medical Officer, B.O.A.C, *Fellow*): He noted that Mr. Pike recognised that with direct approach speeds there was a physiological problem with which the human body could not cope unaided. Captain Hunt did say that they could apply the team technique for oblique approaches, and of course, he was quite right, but there was another problem. They were now getting into the era, or would before very long, when aircraft would operate at such heights that a new visual problem would arise, called space myopia. They had hitherto understood that the eyes when at rest focused on infinity and therefore it was assumed that other aircraft could be seen at a distance, provided that conditions were suitable. It had now been found that at altitude, when the eyes had not got a distant point on which to focus, such as the horizon or clouds, they did not in fact focus at infinity, but at a very much shorter range. Therefore one would not see other aircraft at a distance, and might not see it approaching; he thought it would be a dangerous philosophy to put faith for very long in the theory of being able to see other aircraft outside the cockpit. They had got to remember that they were now getting into the era when the human machine was not capable of dealing with these things with anything like the degree of accuracy or safety that aircraft equipment was.

Peter Masefield (Managing Director, Bristol Aircraft Ltd., *Fellow*): This was one of the most controversial subjects in Aviation today. But he was particularly impressed with one thing. At last, from the manufacturing point of view, the operators seemed to feel that they had been provided with adequate aircraft for this job across the Atlantic. They heard propositions that Met. should be ignored and that could only mean that the aeroplanes were adequate. He took a little leave to doubt that point.

It seemed to him that three things came up from this. The first was safety. He thought they were all impressed with the emphasis which had been placed on that by Mr. Pike and Captain Hunt and others, particularly the collision problems. Obviously the vital fact was to know where one was at any given moment over the ocean, if that fact were known it would help tremendously on safety. That was the background for these proposals of precise tracks, which should be flown regardless of the Met. conditions. One could feel reasonably assured that everything was being done which should be done.

The second point was regularity of getting across when one said one was going. That seemed to be pretty satisfactory. But the third he thought was not being looked at in anything like the same degree. It was economy.

They had heard the word economy mentioned only once that evening, he thought by Sir Frederick Tymms. One could not help feeling pretty horrified by the 120 mile lateral separation and the somewhat odd treatment by one or two of the discussors of the problems of vertical separation. Such separations were totally uneconomic.

Mr. Pike said, and he was very interested to hear it, that operational freedom in the vertical plane was essential, and one would like to endorse that, although Captain Hunt said that "we are throwing away the third dimension." He thought he and Capt. Hunt were thinking in diametrically opposite ways about the third dimension. What Capt. Hunt was saying was that he wanted to use the third dimension to position the aeroplane rigidly to maintain a particular height and never to depart from it unless told to do so. He did not call that using the third dimension, except in a rigid way.

From the economy point of view what was needed was to use the third dimension flexibly and thus to use the economy which was inherent in turbine engines. One of the great advances that they were going to be able to offer from the manufacturing side to the operators in the next few years was the fan-jet. The fan-jet engine would be very much more flexible with its height tolerance. Indeed it might well be as big an advance in the science of that type of operation as the jet was over the piston engine. For the moment economy could be achieved only by flying the aeroplane at its right height. Whether that was in steps or cruise climb it must be pretty close to the ideal if one were not going to sacrifice a lot of economy.

He would like to ask two questions of Mr. Pike. First of all on this point of height separation. What percentage of occasions would he say that aircraft had been prevented from climbing to the height they wanted by the fact that other aeroplanes were occupying a height above them "sitting on their heads"? How was this working out in the normal everyday hurly-burly?

The second question, did Mr. Pike feel that, in the future, they had to throw away any thoughts of pressure pattern flying and of avoiding jet streams? If one of the pure-jet tracks went straight into a 160 knot jet stream would he feel that they must have a good enough aeroplane to battle through it, or would they be able to go round?

Recently he happened to know there was an eighty-eight knot head wind between the Azores and Bermuda which had to be battled against by a particular aeroplane. Would Mr. Pike feel that pressure pattern flying could be allowed to go around such conditions?

Captain Hunt: He thought Mr. Masefield had taken him a little bit too rigidly; what it came to was that absolute freedom to the aircraft in the vertical plane completely denied vertical separation to the controller. Equally well, fixed levels throughout the flight would put a heavy penalty on the operator. Somehow or other he believed the solution would be found by team-work between the controller, the operator and the aircraft designer, with the aircraft being made as flexible as possible so as to make the maximum use of the air space.

Mr. Pike: On the two questions Mr. Masefield had raised, he had no statistics with him, and did not know

the precise extent to which this restriction had affected either the aircraft in his own airline or others. They had to remember that there were serious traffic peaks on the North Atlantic. There were times when people wanted to travel across the Atlantic and because the operators must cater to their wishes they travelled at these popular times. Therefore the aircraft bunched, and Gander was a notorious place Eastbound for difficulties in vertical separation. So far this had been bad, but they had managed to get along by playing around a little with altitudes. When one only had two or three altitudes which one could use, as would the jets, things were going to get serious. Many planners had assumed that the jet was always going to fly high, but of course that was not true. Many operators had realised that the real appeal of the jet was its speed and would want to make use of it by flying at VNO at perhaps only 22,000 ft., right in the turbo-props' and at the top of the piston engines' altitudes. If one wanted to fly level, increasing speed with decreased weight to get to Brussels, Copenhagen, Frankfurt and such places from New York in the minimum time, things were going to get materially worse for A.T.C.

Pressure pattern flying simply meant taking advantage of the presure distribution to reduce the probable time of a flight. Of course this would continue as they would always want to plan on somewhere near the minimum time track. It would not, however, be the minimum theoretical time in many cases, but along the optimum theoretical track and there was no earthly reason why this could not continue. As already mentioned, all the aircraft going in a single direction would probably want to fly somewhere near the same track, but if the deviation could be as little as 10, 15 or 20 miles in the lateral plane it would make very little time difference unless one ran into a jet stream. This of course was a serious possibility and in such cases there was no reason, as he was sure Captain Hunt would agree, why an alternative clearance to another defined track could not be requested. S.A.C. had told them that the turbulence associated with the edges of jet streams could be very unpleasant indeed and they had over 2½ million hours of experience with jet aircraft. With reference to an 88 knots headwind, which seemed rather frightening, the fact was that in a modern jet aeroplane, an 88 knot component all the way across (which was something extreme)only made one hour and a quarter difference in flight time. Fortunately, the manufacturers, or some of them, were putting tankage on to cope with these cases. Without full load one could often put on extra fuel and fly comfortably against an 88 knot wind without too serious an effect on the overall economy.

H. E. Smith (Navigation Superintendent, B.O.A.C.): As the system proposed by Mr. Pike was designed to separate major traffic flows, to some extent the rôle of air traffic services approached that of a monitor and although the ability to communicate at any time was still an essential requirement, a reduction in the present level of mobile communications would undoubtedly result.

He had assumed that such a track system as Mr. Pike had in mind would incorporate the necessary degree of vertical freedom, which would enable jet aircraft to cruise-climb. Nevertheless, the Controller's ability to use the vertical plane restrictively when necessary, existed, just as it did in any "Flight Level" system.

Finally, many of the problems over the North Atlantic today could be traced to the initial phases of flight where systems and procedures were incompatible with those of the North Atlantic air space. For example, the longitudinal separation at a given flight level in the "feeder" airways was ten minutes. The longitudinal separation at the present time for a given track on the North Atlantic was thirty minutes. The resultant build up of traffic at the North Atlantic boundaries inevitably lead to restrictions.

Procedures and standards of any North Atlantic track system must be compatible with the feeder systems.

Mr. Pike: With reference to the last remark his topic was Air Traffic Control over the North Atlantic, not over the world.

Returning for a moment to Mr. Masefield's remarks a point which he omitted to make in his reply was that there were eight or nine references to economy or economics in his paper.

Sir Harold Hall: When the Viscount propeller-turbine was first brought into service, they were told that Air Traffic Control would be rendered useless. In fact, the control system did cope, possibly as a result of the advantages arising from wartime technology.

Now, when introducing the pure-jet transport they were told the same thing. Was this because they were, in fact, running out of technological knowledge?

Mr. Pike: Air Traffic Control systems as at present operated, were running out of stock solutions for the pure jet. They were approaching a precipice (not a slope) at which Air Traffic Control might just give up. He believed this could happen in about two years unless they had a catastrophe to apply the necessary stimulus.

Captain Hunt (*Contributed*): With regard to the question posed by the President as to whether they had run out of ideas for solving air traffic control problems, he would like to say that they still had plenty but that the worry at the present time was getting the machines and equipment in time to put them into effect before very serious delays built up over the Atlantic.

He would say that in the past year or so they had had much greater support from the Ministry of Supply in attempting to meet their needs, but their financiers were still not used to spending what, to them, appeared to be large sums of money on developments for civil aviation, even though they might only be equivalent to a quarter of the price of a modern jet aircraft.

D. L. Thomas (Standard Telecommunications Laboratories) (*Contributed*): As an engineer concerned with telecommunications and similar equipment, there were two comments on Mr. Pike's paper and the subsequent discussion that appeared to be justified.

The first on the rôle the air-to-ground communications should play in a future Air Traffic Control Organisation. On the assumption, following Mr. Pike's suggestions, that more economical use of air space might be achieved by "traffic lanes," determined by destination and type of aircraft, and the use of radio "station-keeping" equipment, the situation arose that very rapid action was necessary on the part of the controller if a breakdown—particularly electrical—occurred on any aircraft. This rapid action could be taken most usefully and rapidly if accurate and "up to the minute" information were available of the position, course, speed, height, and so on, of the aircraft in the vicinity of the one with a "breakdown." This could be achieved if it were assumed that all airborne aircraft were feeding flight data into a computer in reasonably rapid sequence. The controller could ignore this information until an emergency arose, but would have the full situation made available on demand.

It was interesting to note in this context that certain railway drivers had requested that two-way radio communication should be made available to them for use in conditions of poor visibility.

The second point was relevant to the problems of unified control of aircraft over the North Atlantic. This problem could probably be considerably eased if the two sides shared a computer dealing with flight plans and flight data. It could reasonably be assumed that the common equipment would tend to force a common procedure and approach to North Atlantic Air Traffic Control.

Sir Arnold Hall: He thanked the Lecturer for his interesting lecture and welcomed particularly their American friends. He hoped they would attend future meetings.

The Future for Solid Propellant Rockets

by

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1. Introduction

Ten years ago it seemed that the solid propellant rocket engine could make only a limited contribution to rocketry. Although it was simpler and more compact than its liquid propellant rival it suffered from three serious drawbacks. The nozzle was uncooled and so the burning time had to be short, the entire propellant container was subjected to the full combustion pressure and temperature and therefore the inert weight of the engine was high and, since the specific impulse of solid propellants is in general lower than that of liquid propellants (because solids are partially reacted systems) the engine performance was consequently poor, and finally, no means were available for controlling the magnitude and duration of the rocket thrust. These facts were the foundation of the opinion, still held by some people, that solid propellant engines were only suitable as boosters or short burning time sustainers for small missiles.

The liquid propellant rocket engine, on the other hand, had a regeneratively cooled combustion chamber which could withstand the combustion temperature for several minutes and the propellants were contained in separate tanks under a low pressure and pumped into the engine combustion chamber. Therefore the liquid propellant engine had a relatively long endurance and a high overall specific impulse. In addition the thrust could be cut off at any desired moment and, within limits, could also be varied; and so the liquid propellant engine seemed to be the only suitable power plant for long range rockets.

With the successful manufacture of big internal burning charges, which provided thermal insulation for the engine case and thus enabled full use to be made of the "cold strength" of high tensile steels, and the development of refractory lined nozzles, both the performance and endurance of the solid propellant engine were increased sufficiently for it to be able to replace the liquid propellant engine as the sustainer power plant for ground to air missiles. In time the drawbacks of the liquid propellant engine became apparent: it is a relatively complicated device which uses large quantities of reactive and/or volatile liquids that have to be stored and handled along with the missile. Liquid propellant engines take longer to prepare for firing and need the attention of more highly trained personnel. Liquid propellant engines are not so easy to scale up[1, 2] and for very high thrust requirements the engines have to be clustered. Transportation is likely to be the main factor limiting the size of solid propellant engines. Staging with liquids means a greater increase in missile complexity than when staging with solids and also raises the problem of starting under zero gravity.

Improvements in the solid propellant engine have continued and with the successful development of the large case-bonded charge of high energy composite propellant, the long range solid propellant rocket became feasible. The fact that solid propellants are now envisaged for use in all types of military missile even up to I.C.B.M.s[3] shows that the early criticisms of poor performance and lack of controllability of thrust are now no longer valid and that the virtues of compactness, simplicity and reliability are enabling solid propellant engines to steadily replace their liquid propellant rivals in many missile applications.

It is the purpose of this paper to show how the performance of solid propellant rockets has improved during the past decade and also how they can provide controlled thrust to meet any missile requirement.

2. The Improvement in Solid Propellant Rocket Performance

Figure 1 shows a typical Second World War solid propellant rocket which would have a burning time of only a few seconds and an overall specific impulse of 60-70 lb. sec./lb. Such figures do not compare at all with similar ones (burning time 70 secs. and overall specific impulse 165 lb. sec./lb.)* for the V2 power plant, a contemporary liquid propellant engine. It is easy to see how the "V2 school of thought" arose which argued that solid propellants would never be any use for long range rockets.

However, by using an internal burning propellant charge, which protects the engine case from the hot gases, and by coating the rear end of the engine case and the nozzle with insulating/refractory material a solid propellant engine of the type shown in Fig. 2 can be produced with an overall specific impulse in the region of 160-170 lb. sec./lb. and a burning time in excess of half a minute.

Cordite propellants had been under development for use in guns many years before serious work was started on the solid rockets to be used in the Second World War and so, naturally, during the early stages of solid rocket development cordite propellants were used almost exclusively. It was quickly realised that the best performances could only be obtained if the propellant charge could be stuck to the engine case wall. But early attempts to construct rockets in this way failed[5]

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*Taken from data given in Ref. 4.

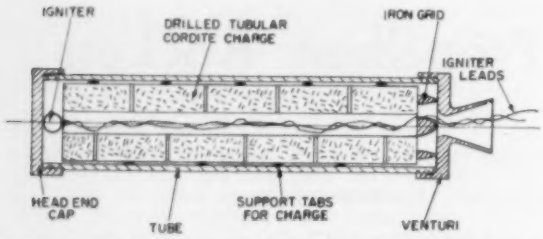


FIGURE 1. Typical Second World War solid propellant rocket with loose charge. Overall specific impulse 60-70 lb. sec./lb.

because cordite was not a sufficiently pliable propellant to accommodate the difference in thermal expansion and contraction between the case wall and the propellant when the rocket was subjected to a fluctuating temperature. Thus early solid propellant engines of the types shown in Figs. 1 and 2 had to use loose charges. For a given weight of propellant, engines using loose charges will be bigger and have higher inert weights than those using case-bonded charges; there are three reasons for this. Firstly, in order to be able to insert a loose charge into the engine the case must have one end, usually the nozzle end, open to the full diameter of the charge and such an engine case will be heavier than one designed for a case-bonded charge where the nozzle end opening is only about three fifths of the full charge diameter.† Secondly, a loose charge must have an inhibitory plastic coating on the outside surfaces that are not intended to burn and such a coating occupies space that could otherwise be filled with propellant and adds to the inert weight of the engine. Thirdly, the internal diameter of the engine case must be slightly bigger than the external diameter of a loose charge in order to allow for the differential expansion between the charge and the case and also to allow for the variation in charge and case diameter due to manufacturing imperfections. The provision of this clearance space causes a further increase in engine size and weight.

Now the composite propellants, which are an intimate mixture of a ground inorganic oxidant and an organic fuel binder, are usually pliable enough to cope with the effects of temperature fluctuation and so they can be satisfactorily case-bonded. The propellant is cast inside the engine case and around a metal former as a liquid and then cured into a rubbery mass. By means of surface treatments the charge is made to adhere tenaciously to the engine case wall but not to the metal former. The latter is then withdrawn when the curing process is complete leaving a central conduit of the required shape. Some properties of a range of typical composite propellants[6] are given in Table I.

By using high tensile alloy steels with strength to weight ratios of 820,000 in. and refractory lined nozzles in combination with a case-bonded composite propellant system, solid propellant engines with mass ratios as high

†As explained later case-bonded charges are formed inside the engine case by a casting process and so the nozzle end opening need only be big enough to accept the charge former which is about three-fifths of the charge diameter.

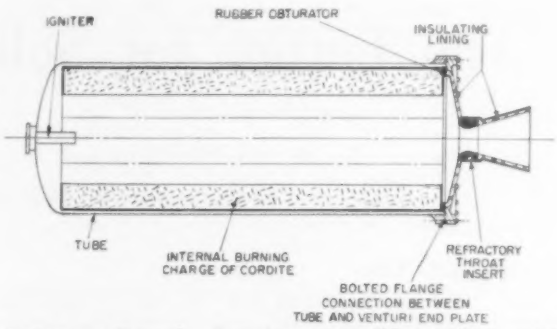


FIGURE 2. Example of an improved solid propellant rocket engine with a loose internal burning charge of cordite. Overall specific impulse 160-170 lb. sec./lb.

as 0·93[7] are attainable. Even better figures than this should be possible using fibre glass of strength to weight ratio 1,190,000 in.[8] for the engine case. A mass ratio of 0·93 and the propellant system referred to in Table I will enable solid propellant engines with overall specific impulses as high as 223 lb. sec./lb. to be produced (*see* Fig. 3). High performances like these have been made possible by the successful development of high energy case bondable composite propellants, very high strength materials of construction and refractory lined nozzles. However, much has also been gained by optimisation studies. The performance characteristics of a solid propellant rocket engine are determined by the type of propellant and the shape and size of the engine, and so for any specific task it is possible to design an engine of minimum weight by selecting a suitable propellant and engine case shape. Such optimisation studies show that if solid propellant engines are required as boosters at low altitudes they should be fairly slender in shape and operate at high combustion pressures. If, on the other hand, they are required for use at high altitude, *e.g.* for the later stages in ballistic missiles or high altitude test vehicles then they should be of squat shape and operate at low combustion chamber pressures. The figures for mass ratio quoted refer to engines in the second category designed for use at high altitudes.

It is interesting to examine one curve from a graph produced by A. V. Cleaver[9] in 1951, concerning the relative performances of solid and liquid propellant engines used for assisted take-off purposes, which is reproduced in Fig. 4. Values of (lb. weight empty/lb. thrust) are plotted against burning time, in seconds,

TABLE I.

SOME BALLISTIC PROPERTIES OF A CASTABLE COMPOSITE PROPELLANT SYSTEM

†Sea level specific impulse in lb. sec./lb.	175 - 240
Specific weight	0·055 - 0·063
Burning rate at 1000 lb./in.² in in./sec.	0·1 - 0·5
Exponent n in burning rate law*	0·1 - 0·4

*The burning rate of a solid propellant is proportional to the pressure over its surface raised to the power n.

†Expansion from 1,000 lb./in.²

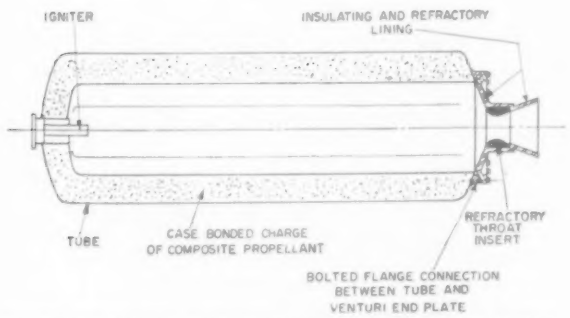

IGNITER
INSULATING AND REFRACTORY LINING
TUBE
CASE BONDED CHARGE OF COMPOSITE PROPELLANT
REFRACTORY THROAT INSERT
BOLTED FLANGE CONNECTION BETWEEN TUBE AND VENTURI END PLATE

FIGURE 3. Modern solid propellant rocket with case-bonded charge of composite propellant. Overall specific impulse up to 223 lb. sec./lb.

for solid rocket systems. Also given in Fig. 4 is a line for a modern case bonded composite propellant rocket having an engine mass ratio of 0·93 and a propellant specific impulse of 240 lb. sec./lb. The improvement in the position of solid rockets is indeed remarkable.

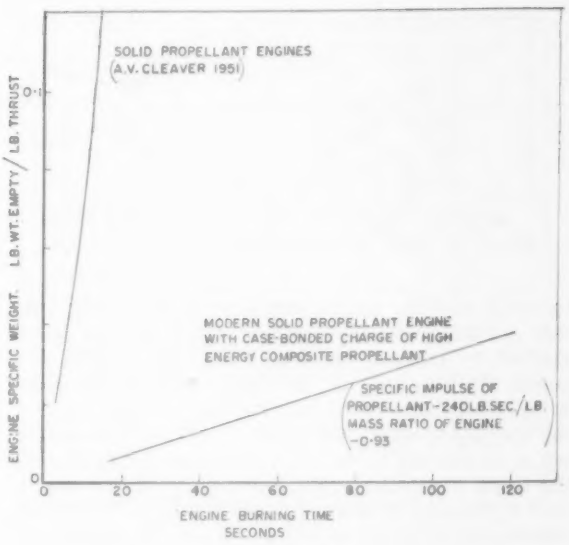


FIGURE 4.

2.1. THRUST CONTROL FOR SOLID PROPELLANT ROCKET ENGINES

It has been shown that solid propellant engines have the performance necessary for long range rockets and so the second basic criticism, namely, that they lack controllable thrust, must now be met.

2.2. CONTROL OF THRUST DIRECTION

An extensive study of jet deflection methods has been made by Fraser and Rowe[10] who have given information about three methods which would be applicable to solid propellant rockets.

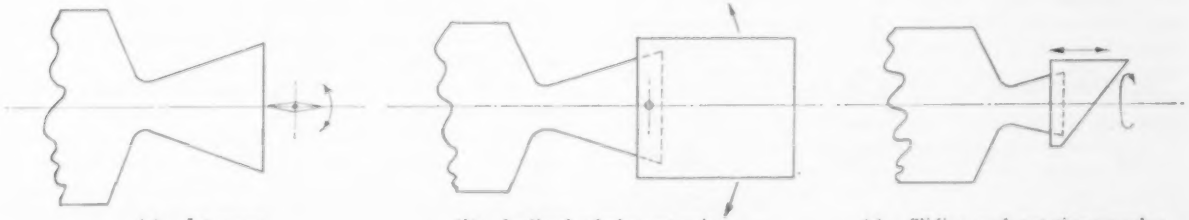
(*i*) Jet vanes.
(*ii*) The inclined tubular extension.
(*iii*) The sliding bevelled extension or ungulus.

Jet vanes are the least attractive method of the three because they cause thrust losses whether the jet is being deflected or not and they are subject to severe erosion. Although the inclined tubular extension is the heaviest of the three devices and the control force is high and varies in a complicated way it is probably the best system, for there is no loss of axial thrust when the tube is not inclined and the erosion of the extension should not be severe because it is only in contact with the outside boundary of the jet. The sliding ungulus is easily the simplest and lightest device, but the nozzle must be under-expanded for it to work and with a large ballistic missile engine burning at say twenty atmospheres pressure this means a low expansion ratio (2·5) for the nozzle, if the device is to be useful at launch, which in turn means that the nozzle is going to be grossly under-expanded at high altitude with consequent serious losses in thrust when the missile is gaining most of its speed. Sketches of the three jet deflection devices are given in Fig. 5; the small expansion ratio of the ungulus nozzle is apparent.

Changes of engine thrust direction may also be obtained by swivelling auxiliary jets or by swivelling the engine nozzle and such systems will have negligible thrust losses and small control forces. With auxiliary jet systems it is better to provide two or four small engines that can be mounted in gimbals than to try to use gas tapped from the main engine, because of the plumbing difficulties involved with gases at temperatures over 2,000°C. A swivelling engine nozzle would be lighter than an auxiliary jet system, but there is the problem of providing a sliding gas tight seal at high pressures and temperatures. Some sketches of possible devices are given in Fig. 6.

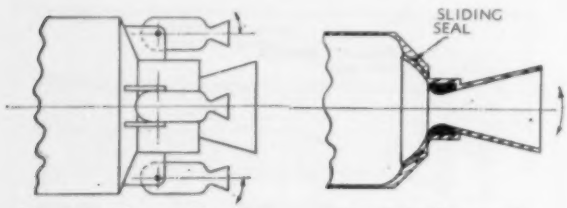
2.3. CONTROL OF THRUST—THRUST CUT-OFF

For accurate control of the velocity of a ballistic missile warhead it must be possible to stop the engine



(*a*). Jet vanes. (*b*). Inclined tubular extension. (*c*). Sliding and rotating ungulus.

FIGURE 5. Some methods of jet deflection.

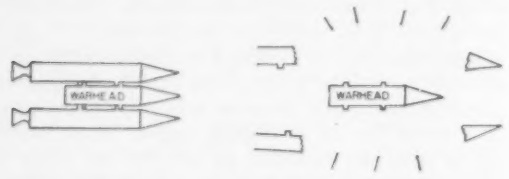


(*a*). Swivelling auxiliary jets. (*b*). Swivelling nozzle.

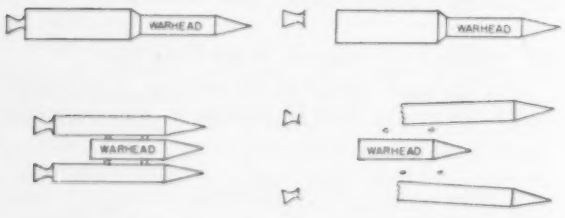
FIGURE 6. Other methods of thrust direction control.

thrusting at will. It has been known for a long time that a burning solid propellant charge can be extinguished by suddenly reducing the pressure within the engine chamber and use has been made of this effect in so called "interrupted burning" experiments to study the burning of solid propellants.[11] The effect may be put to further use to provide a technique for cutting off the thrust of a solid propellant engine. If the engine case is designed so that extra gas venting holes can be opened suddenly and at will it will then be possible to suddenly reduce the engine pressure, extinguish the propellant charge and so cut off the engine thrust. Extra venting holes can be provided at either the front end, rear end, or side of the engine case and they can be covered until needed by plates secured with explosive bolts. When extra venting holes are suddenly opened there is a brief increase in the rate of discharge of gases from the engine which can cause a peak thrust several times bigger than the normal engine thrust. This peak thrust could damage a missile unless precautions are taken. Fig. 7 shows a variety of missile configurations designed to allow the engine thrust to be cut off by interruption of burning without damaging the missile.

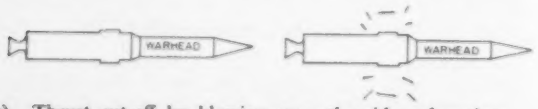
Opening venting holes at the front of the engine can



(*a*). Thrust cut-off by blowing off front ends of engines.

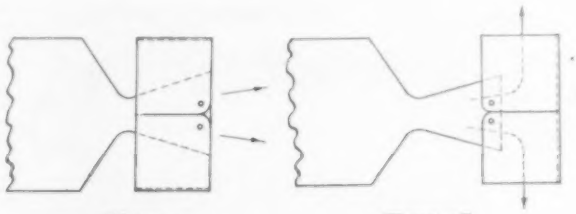


(*b*). Thrust cut-off by blowing off rear ends of engines.



(*c*). Thrust cut-off by blowing open the sides of engine.

FIGURE 7. Thrust cut-off by interruption of burning.



Thrust on. Thrust off.

FIGURE 8. Thrust cut-off by spoiler plate.

only be done with a wrap-round layout as shown in Fig. 7(*a*). The attachments between the engines and the warhead and guidance dart in the middle are only secure when the engines thrust forward. When the front ends of the engines are blown off there is a brief reversal of thrust and all the engines will disengage from the warhead and be extinguished. Provided that the front ends of the engines are all released simultaneously the warhead will not be disturbed from its course.

When venting is done at the rear end the engines can either be behind or alongside the warhead dart as shown in Fig. 7(*b*). With the engines alongside the warhead dart the fastenings between the two can be designed so as to shear at a thrust slightly bigger than the normal engine thrust so that the engines will break away from the warhead dart as soon as interruption is carried out and the latter will not experience the full peak thrust. If the engine is placed directly behind the warhead then some form of shock absorber system would be necessary to attenuate the peak thrust.

If identical venting holes are opened in each side of the engine case simultaneously then the peak thrust produced by each hole will balance out and no peak axial or lateral thrust will occur. In this case (Fig. 7(*c*)) the engine can be placed behind the warhead without an intermediate shock absorber system.

The thrust of a solid propellant rocket engine can be reduced to nothing, without extinguishing the propellant charge, by placing spoilers in the jet. A device similar to the one described by Hayne Constant[12] should suffice (*see* Fig. 8). If separation between the warhead and the rocket engine were necessary the spoilers could be arranged to provide a slight reversal of thrust which would pull the engine backward. There are two disadvantages of spoiler systems: firstly, they will be subjected to severely erosive conditions and so they will have to be made of some material like molybdenum or tungsten; secondly, as the engine is still burning after thrust cut-off large quantities of hot propellant gases will be blown over the rear end of the missile and will quickly damage the missile structure unless adequate heat shields are provided.

With a wrap-round missile layout there is one further possibility for thrust cut-off—the warhead dart can be dropped behind when the required warhead velocity has been reached; this technique is shown in Fig. 9. The jets of the engines must be splayed out to ensure that they do not push the warhead off course when it is released and so there will be a slight loss of forward thrust with this system.

FIGURE 9. Thrust cut-off by releasing the warhead.

2.4. CONTROL OF THRUST MAGNITUDE

If the magnitude of the engine thrust could be accurately controlled within wide limits there would be little need for thrust cut-off devices. Other advantages accrue from continuously variable thrust: a single stage missile can be designed to have a high net launching acceleration (1·5g to 2·0g), to get itself quickly away from the launching area, and yet a low average acceleration throughout flight which would minimise aerodynamic drag losses and ease the environment for the guidance equipment.

The equilibrium pressure in a burning solid propellant rocket is given by the equation[13]

$$P=\left(\frac{A_b}{A_t}\right)^{\frac{1}{1-n}}\left\{\frac{c}{N_D}(\rho_s-\rho_g)\right\}^{\frac{1}{1-n}} \quad . \quad . \quad (1)$$

where

P is the equilibrium pressure
A_b is the burning surface area of the propellant charge
A_t is the nozzle throat area
ρ_s is the density of the solid propellant
ρ_g is the density of the gases within the rocket
N_D is a constant equal to

$$\left\{\frac{\text{mass rate of discharge of propellant from rocket}}{\text{rocket pressure} \times \text{nozzle throat area}}\right\}$$

c and n are constants in the propellant burning rate law which states that the linear burning rate of a solid propellant is equal to the pressure over its surface raised to the power n and multiplied by the quantity c.

If the thrust coefficient of the nozzle of the same rocket is C_F then the thrust is

$$F=C_F A_t\left(\frac{A_b}{A_t}\right)^{\frac{1}{1-n}}\left\{\frac{c}{N_D}(\rho_s-\rho_g)\right\}^{\frac{1}{1-n}} . \quad (2)$$

Alternatively

$$F=C_F A_b^{\frac{n-1}{1-n}}\left(\frac{A_b}{A_t}\right)^{\frac{n}{1-n}}\left\{\frac{c}{N_D}(\rho_s-\rho_g)\right\}^{\frac{1}{1-n}} . \quad (3)$$

Consider first the case of a rocket engine whose nozzle geometry is fixed but whose propellant burning surface area changes. If the quantities C_F, N_D and $(\rho_s-\rho_g)$ are assumed to be but little affected by changes in engine pressure then the change in engine thrust accompanying a change in propellant burning surface area is given more readily by equation (2) *i.e.*

$$F\propto\left(\frac{A_b}{A_t}\right)^{\frac{1}{1-n}} . \quad . \quad . \quad . \quad (4)$$

When the propellant burning surface area is constant and thrust variation is produced by changing the throat area of the nozzle then, if C_F, N_D and $(\rho_s-\rho_g)$ are still assumed to be constant, the engine thrust is more appropriately described by the relation

$$F\propto\left(\frac{A_b}{A_t}\right)^{\frac{n}{1-n}} . \quad . \quad . \quad . \quad (5)$$

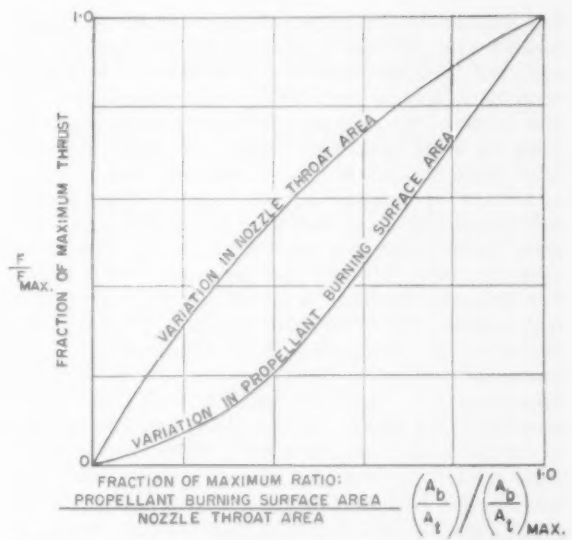


FIGURE 10. Thrust variation graph for engine with a propellant of burning rate exponent 0·4.

Equations (4) and (5) are illustrated graphically in Fig. 10 and it is clear that a fixed nozzle system will produce a wider variation of thrust for a given range of values of (A_b/A_t), and hence a given range of engine burning pressures, than the variable throat area nozzle system. However, the fixed nozzle arrangement has the disadvantage that the variations in thrust which it produces must be pre-set and cannot be controlled during flight. The best solution for a variable thrust solid propellant engine therefore lies in having a combination of both techniques, *i.e.* an engine whose propellant burning surface area changes and so produces the major variation in thrust and whose nozzle throat area can be slightly adjusted so as to provide adequate thrust control during flight.

A design for a missile with variable thrust is sketched in Fig. 11. The engine contains a propellant charge, which has a steadily diminishing burning surface area, and is fitted with a ring of nozzles, some variable, some fixed. By opening the variable throat area nozzles on one side of the engine and closing those on the other, the position of the engine thrust resultant can be moved from side to side, thus providing a convenient method for steering the missile and so avoiding the need for jet deflection devices. Details of a suitable variable throat area nozzle are also given in Fig. 11. Nozzles with sliding pintles have been discussed for use with aircraft rockets[14] and ram-jets.[15]

Conclusion

Big rocket engines can be used to propel either long range terrestrial weapons or space vehicles. For the

first application the propulsion unit should be simple, reliable, safe and easy to operate, have a relatively low cost per mission, require the minimum of ground support equipment and highly trained personnel and also require the minimum time for preparation for firing—a solid propellant engine is more likely to fulfil these conditions. It is apparent that this fact is already appreciated in the U.S.A. where several ballistic missiles fitted with solid propellant engines are under development and some are envisaged as replacements for those having liquid propellant power plants. For example, *Sergeant* is to be the solid propellant replacement for *Corporal*[16] and *Pershing* for *Redstone*.[17] The U.S.A.F. is developing a solid propellant version of *Thor*[18] and an I.C.B.M. called *Minuteman*.[19] Apprehensive about having liquid propellants on board ship the U.S. Navy has decided to develop a solid propellant I.R.B.M. called *Polaris*.[20] Thus solid propellants are playing an ever increasing part in the field of military rocketry leaving liquid propellants, for the moment, to cope with the propulsion of the longest range military rockets and space vehicles where maximum performance is required. With the increasing use of thrust control devices solid propellant rockets will prove themselves to be the most flexible rocket engines yet, capable of providing tailor-made thrust to meet any vehicle requirement. Big increases in propellant specific impulse can eventually be expected from the use of free radicals and since free radicals will only be stable in a highly deactivated state, *e.g.* in a solid system, the high energy propellants of the future for long range military rockets and space vehicles are likely to be solid propellants.[21] The future for solid propellant rocket engines is therefore very bright indeed.

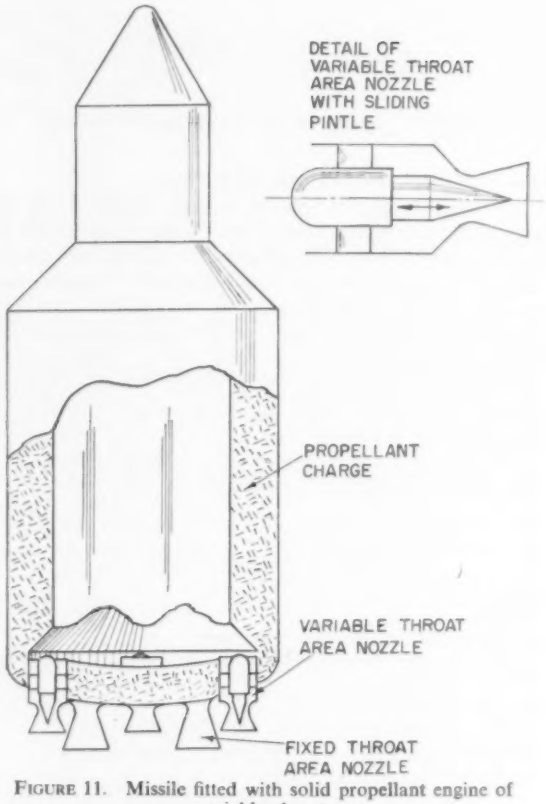


FIGURE 11. Missile fitted with solid propellant engine of variable thrust.

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(*Attention is drawn to the "Note on Liquid and Solid Propellants for Rockets" by* E. G. D. ANDREWS *and* A. W. T. MOTTRAM *on p.* 265.—*Ed.*)

The Present Status of Aircraft Stability Problems in the Aeroelastic Domain

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SUMMARY: Recent developments in the study of the effects of structural flexibility on aircraft stability and control (with particular reference to dynamic stability) are discussed.

The relevant literature, relating to both theoretical and experimental work, is reviewed against the theoretical background outlined in Section 2, with a view to assessing the importance of these effects and establishing how elaborate a mathematical treatment is necessary to predict them with reasonable accuracy.

The advantages of an integrated approach to this and associated aeroelastic problems, whereby the solutions to several related problems may be obtained as special cases of a more generalised problem, are briefly discussed.

1. Introduction

In his classic paper, *The Expanding Domain of Aeroelasticity*[1], Collar indicated how various types of problems (involving at least two of the three kinds of force—aerodynamic, elastic and inertial), which had hitherto been dealt with in their own "watertight compartments," were tending to coalesce into a single subject which might be defined as "the dynamics of a deformable aeroplane." The title of the subject, as Collar pointed out, at once suggests (to the mathematician at least) the formal solution of the problems which it comprises. To quote from Collar's paper: —

> "We select as generalised co-ordinates quantities defining the translational and angular freedoms of the aeroplane as a rigid body; we add co-ordinates representing the control surface angles, tab angles, stick and pedal movements, and with these we include co-ordinates sufficient to describe the modes —normal or otherwise—of elastic deformation of the aircraft. We then derive, in terms of the inertia and elastic properties of the aircraft and the air forces, the complete Lagrangian equations of motion, including in the appropriate equations forcing terms representing mechanical vibration impulses, gusts, landing impacts, pilots' efforts, and so forth."

Such a procedure leads to a set of simultaneous differential equations, probably in twenty to thirty degrees of freedom, the solution of which would have been prohibitively laborious at the time Collar wrote, but which, as he then forecast, has now become feasible, thanks to the advent of powerful computational aids. But the availability of such aids does not mean that we should automatically adopt this all-embracing method of dealing with the problems now encompassed within the expanded domain of aeroelasticity. In the past it was the fact that the coupling terms in the equations of motion were few (or weak) that justified the treatment as separate entities, of the various subjects then considered to be within, or on the fringes of, the aeroelastic domain. To the extent that such couplings remain of negligible magnitude, it is still desirable to break down the complete set of equations into mutually independent groups which, although possibly containing more elements than hitherto, are nevertheless considerably more tractable than the complete set.

As suggested by Collar, coupling is likely to be strongest between subjects which are adjacent in the "frequency spectrum" so that in seeking to extend the theory of one of the original (primary) subjects it is logical to consider a sufficient number of equations to cover that subject and its immediate neighbour(s) in the spectrum. This implies modifying the equations which formerly governed the problem, by the introduction of appropriate coupling terms, corresponding to the one or more additional equations which must also be introduced. Such a technique for unifying the subject, while avoiding the somewhat frightening complexity inherent in dealing with the whole field at once, "offers rather the advantage that we may study the various aspects in relation to their associated subjects by a standard method of attack."

There have been developments along these lines in various parts of the aeroelastic domain in the past decade and a review of the whole field would be interesting and instructive. However, it is not the intention, in this paper, to make such a comprehensive survey but rather to consider what has been going on in the sector which contains the important subject of aircraft dynamic stability.

Dynamic stability appears at the low frequency end of Collar's frequency spectrum and is thus to be associated with the so-called "steady state" aeroelastic problems on the one hand and with gusts and possibly with flutter on the other. Of the steady state problems, aileron reversal has been dealt with as an aerodynamic-elastic force problem ever since the birth of aeroelasticity, while the effects of structural deformability on static longitudinal* stability and on the steady

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*Effects on lateral stability have attracted less attention, presumably because they are in general less critical.

manoeuvrability criteria of Gates and Lyon have been fairly exhaustively studied in the past ten years or so. The methods available for investigating such effects were briefly reviewed by the author in 1954[2]. As regards gusts, already in 1946, Collar (*loc. cit.* Section 6.2.3) could report a case where gust effects on a particular aeroplane were treated as a complete aerodynamic-elastic-inertia force problem, taking account of aeroplane response and of a large number of elastic freedoms for the structure. It is not intended to discuss recent developments in the treatment of gust problems, but as evidence of the continuing appreciation of the importance of aeroelastic effects in such problems, reference may be made to papers by Goland, Luke and Kahn[3], Houbolt and Kordes[4] and Yeh and Martinek[5]. In each of these papers, the degree of freedom of heaving motion is included; in the first of them, wing bending and twist are also included, while in the second and third respectively, wing bending and wing twist are separately considered.

We turn now to the relationship between aircraft dynamic stability and flutter. The theory of the former subject was built up on the assumption that only aerodynamic and inertia forces were involved, the exclusion of elastic forces being justified on the grounds that the frequencies of the aircraft oscillatory modes were normally much lower than those of the elastic modes. Flutter is, of course, essentially concerned with all three types of force, but for a long time, direct association of flutter problems with aircraft stability problems was usually avoided (some exceptions were cited by Collar, *loc. cit.* Sections 6.1.1.1 and 6.1.1.3) by the assumption that it was unnecessary to introduce the body freedoms of the aeroplane as a whole into the flutter problems. This outlook has been modified since the introduction of swept wings and in present day flutter investigations, the effect of rigid-body freedoms is often considered.

Workers in the field of aircraft dynamic stability appear to have been slower to recognise any need to modify their assumptions and it is only in the past three or four years that evidence, in the shape of published papers, has appeared to show that they have, at last, considered it desirable to include the effects of structural deformability in their investigations.† The author had queried whether the time had arrived to consider such effects in the paper already referred to[2] and returned to the question again in a joint paper with James[6] in 1955, by which time, at least one paper[7] had appeared to indicate the awakening of American interest in the problem. Subsequent N.A.C.A. papers[8, 9, 10, 11, 20] had given particulars of further theoretical and experimental work in this field, while quite recently a few British reports[12, 13, 14, 15] dealing with these topics have been issued.

†It may be remarked that W. J. Duncan, in his text book on "Control and Stability of Aircraft" (*Cambridge University Press*, 1952), went as far as developing the complete dynamical equations for longitudinal-symmetric motion of an aircraft with flexible fuselage but used them only to study the effect of fuselage flexibility on static stability and to illustrate the "quasi-static" approach to dynamic problems, which will be discussed later in this paper (Section 2.1.4).

The main purpose here is to review this recent literature and to see to what extent it provides the answers to the following questions: —

(*a*) Do elastic forces play an important part in determining the dynamic stability characteristics of current or projected aircraft?

(*b*) If so, how comprehensive a mathematical treatment is necessary to estimate these effects with reasonable accuracy?

(*c*) To what extent are Collar's claims as to the advantages of the integrated approach endorsed by recent work?

2. Theoretical Background

To discuss in general terms what has been done in the reports referred to and, in particular to understand precisely what is implied by certain "approximate methods" and "special forms of the equations of motion," it appears desirable to indicate the general form assumed by the equations of motion when elastic effects are included. Attention will be confined here to the equations of longitudinal-symmetric motion. British non-dimensional notation, which is basically that of R. & M. 1801[16], extended and modified by Neumark[17, 18] and others at R.A.E. will be used. It will be assumed that wing mean chord, $\bar{c}$, rather than tail arm is used as representative length.

For the rigid aircraft, the relevant equations for motion induced by elevator deflection may be written*:

$$\left.\begin{array}{lll} (D-x_u)u & -x_w w & +k\theta=0 \\ -z_u u+\left\{\left(1-\frac{z_{\dot{w}}}{\mu_1}\right)D-z_w\right\}w-\left\{\left(1+\frac{z_q}{\mu_1}\right)D-k\tan\gamma_e\right\}\theta= & z_\eta\eta & \\ \kappa u & +(\chi D+\omega)w & +D(D+\nu)\theta=-\delta\eta \end{array}\right\} \quad (1)$$

The most practicable method of taking account of structural flexibility is to employ the method of semi-rigid representation, as described by Duncan in his text-book (*loc. cit.*, Sections 12.2 and 12.4) and applied to the problem of fuselage flexibility.

In general, application of this method involves the introduction of several non-dimensional distortional co-ordinates $h_1, h_2, \ldots, h_n$ which, in conjunction with the rigid aircraft perturbations u, w and θ, describe the dynamic system. The number of dynamic equations is increased from three (equations (1)), to $(3+n)$. The rigid aircraft equations (1) will be modified by the introduction of coupling terms corresponding to each of the distortional co-ordinates h_r, while to each such co-ordinate will correspond one additional equation which will, in general, contain coupling terms between the given co-ordinate and the other $(n+2)$ co-ordinates of the system. For our purpose it will suffice to suppose that there is only one distortional co-ordinate which we denote by h. The equations of motion now assume the form

*Throughout this paper u and w are used to denote increments of velocity non-dimensionalised with respect to V, the undisturbed flight speed. These are usually denoted by $\hat{u}$ and $\hat{w}$ but the circumflexes are omitted to facilitate printing. Similarly q is used for $\hat{q}$.

$$(D-x_u)u \quad -x_w w \quad +k\theta \quad -\left(\frac{x_{\dot h}}{\mu_1}D+x_h\right)h = 0 \qquad 2(i)$$

$$-z_u u+\left\{\left(1-\frac{z_{\dot w}}{\mu_1}\right)D-z_w\right\}w \quad -\left\{\left(1+\frac{z_q}{\mu_1}\right)D-k\tan\gamma_e\right\}\theta \quad +\left\{\frac{P_{zh}}{\mu_1}D^2-\frac{z_{\dot h}}{\mu_1}D-z_h\right\}h = z_\eta\eta \qquad 2(ii)$$

$$xu \quad +(\chi D+\omega)w \quad +D(D+\nu)\theta-\left\{\frac{P_{\theta h}}{i_B}D^2+\frac{m_{\dot h}}{i_B}D+\frac{\mu_1}{i_B}(m_h-P_{zh}k\tan\gamma_e)\right\}h = -\delta\eta \qquad 2(iii)$$

$$-f_u u \quad +(P_{zh}D-f_w)w-\left\{\frac{P_{\theta h}}{\mu_1}D^2+\left(P_{zh}+\frac{f_q}{\mu_1}\right)D-P_{zh}k\tan\gamma_e\right\}\theta \quad +\left\{\frac{P_{hh}}{\mu_1}D^2-\frac{f_{\dot h}}{\mu_1}D-(f_h-\bar f_h)\right\}h = f_\eta\eta \qquad 2(iv)$$

where P_{zh}, $P_{\theta h}$, P_{hh} are generalised inertia coefficients appertaining to the part of the structure which is involved in displacements characterised by the co-ordinate h. The h and $\dot h$ derivatives in the first three equations are of aerodynamic origin, as are f_u, f_w, f_q and $f_{\dot h}$ in the fourth equation. The structural stiffness effect in this last equation is compounded of two terms, f_h and $\bar f_h$ which are respectively of aerodynamic and elastic origin; $\bar f_h$ will be inversely proportional to the kinetic pressure $\frac{1}{2}\rho V^2$.

The manner in which the elastic-inertia coupling terms involving P_{zh} and $P_{\theta h}$, occur in the equations of motion is worth noting. It will be seen that terms of the form $P_{zh}D^2h$ and $P_{\theta h}D^2h$ respectively, in the normal force and pitching moment equations are matched by terms of the form $P_{zh}D(w-\theta)$ and $P_{\theta h}D^2\theta$ respectively in the elastic mode equation. That this is true in the particular case of an aircraft with fuselage bending as the sole distortional mode, is readily verified from Duncan's analysis.* A proof that it is true in the general case is given in the Appendix.

2.1. ADAPTATION OF THE EQUATIONS FOR THE STUDY OF VARIOUS KINDRED PROBLEMS

By considering some special cases, involving various approximations in equation (2), we may arrive at the formal statement and, in some cases, at the formal solution of various problems associated with that of dynamic stability of the flexible aircraft. In so doing we become aware of the advantages of the "integrated approach" whereby the solutions of several kindred problems are obtained as by-products in the investigation of a more complicated problem.

2.1.1. *Dynamic response of the rigid aircraft*

For the rigid aircraft, $h\equiv 0$, the last of equations (2) vanishes and the remaining three reduce to equations (1) which is the standard set of equations governing the response of the rigid aircraft to elevator control.

*Note: A term $-qV\,\Sigma f\,(x)\,\delta m$ appears to hav been omitted from the left-hand side of Duncan's equation (12.5, 9).

2.1.2. *Short-period response of the flexible aircraft (semi-rigid solution)*

In considering short-period response, the forward speed is assumed to remain unaltered ($u\equiv 0$); at the same time it is usual to consider the equilibrium flight path to be horizontal ($\gamma_e=0$). Then if $D\theta$ is replaced by q, the motion of the flexible aircraft is governed by the following set of three equations:

$$\left\{\left(1-\frac{z_{\dot w}}{\mu_1}\right)D-z_w\right\}w \quad -\left(1+\frac{z_q}{\mu_1}\right)q \quad +\left\{\frac{P_{zh}}{\mu_1}D^2-\frac{z_{\dot h}}{\mu_1}D-z_h\right\}h = z_\eta\eta \qquad 3(i)$$

$$(\chi D+\omega)w \quad +(D+\nu)q-\left\{\frac{P_{\theta h}}{i_B}D^2+\frac{m_{\dot h}}{i_B}D+\frac{\mu_1 m_h}{i_B}\right\}h = -\delta\eta \qquad 3(ii)$$

$$(P_{zh}D-f_w)w-\left\{\frac{P_{\theta h}}{\mu_1}D+\left(P_{zh}+\frac{f_q}{\mu_1}\right)\right\}q+\left\{\frac{P_{hh}}{\mu_1}D^2-\frac{f_{\dot h}}{\mu_1}D-(f_h-\bar f_h)\right\}h = f_\eta\eta \qquad 3(iii)$$

whose characteristic equation is of fourth order† and may be written

$$F(\lambda)\equiv\lambda^4+B'\lambda^3+C'\lambda^2+D'\lambda+E'=0 \quad . \qquad (4)$$

It may be noted that for a fixed aircraft weight, at a given altitude, neglecting compressibility effects, the only coefficient in equations (3) which depends on speed (or kinetic pressure) is $\bar f_h$; by inspection it is clear that the coefficient B' in (4) will not involve $\bar f_h$ and it is therefore independent of kinetic pressure. This implies that the total damping of the system is invariant with kinetic pressure, so that any change in the damping of the aircraft mode must be accompanied by an equal and opposite change in damping in the structural mode (*see* next section).

†At first sight it might be thought that this set of three second order equations would yield a characteristic equation of sixth order. However, it will be noted that all the coefficients of w and q are of first or zero order only. Hence, although the coefficients of h are or second order, no term of order higher than four will arise when the determinant of coefficients is expanded. It follows that the general solution of equations (3) will contain four arbitrary constants and that in obtaining a particular solution, four initial conditions must be specified (*e.g.* initial values of w, q, h, and Dh).

2.1.3. *The rigid aircraft short-period mode and the "structure-alone" mode*

Equations (3) represent the motion resulting from the coupling of the *rigid aircraft short-period mode* given by

$$\left.\begin{aligned}\left\{\left(1-\frac{z_{\dot w}}{\mu_1}\right)D-z_w\right\}w-\left(1+\frac{z_q}{\mu_1}\right)q&=z_\eta\eta\\(\chi D+\omega)\,w\quad+(D+\nu)\,q&=-\delta\eta\end{aligned}\right\}\quad .\qquad (5)$$

and what may be called the *"structure-alone" mode* given by

$$\left\{\frac{P_{hh}}{\mu_1}D^2-\frac{\bar f_h}{\mu_1}D-(\bar f_h-\bar f_h)\right\}h=f_\eta\eta\quad .\qquad (6)$$

This represents the motion of the flexible part of the structure which would occur if the aircraft centre of gravity were constrained to move in a straight line at all times, with pitching oscillations suppressed. It serves as a datum condition in studying the effects of short-period coupling on the structural mode. Natural vibrations of the flexible structure in vacuo would be characterised by the equation

$$\frac{d^2h}{dt^2}+\frac{\bar F_h}{mP_{hh}}h=0\quad .\quad .\qquad (7)$$

where m is the mass of the aircraft and $\bar F_h$ is the generalised structural stiffness from which the non-dimensional derivative $\bar f_h$ in equation (2(*iv*)) is derived, through the relationship $\bar f_h=\bar F_h\frac{\bar c}{\rho SV^2}$.

If the characteristic equations for (5) and (6) are expressed respectively as

$$F_1(\lambda)\equiv\lambda^2+G_1\lambda+H_1=0\quad .\quad .\qquad (8a)$$

$$F_2(\lambda)\equiv\lambda^2+G_2\lambda+H_2=0\quad .\quad .\qquad (8b)$$

then it may be anticipated that $F(\lambda)$ in equation (4) will factorise into two quadratics

$$F_1'(\lambda)\equiv\lambda^2+G_1'\lambda+H_1'=0\quad .\quad .\qquad (9a)$$

$$F_2'(\lambda)\equiv\lambda^2+G_2'\lambda+H_2'=0\quad .\quad .\qquad (9b)$$

which, for low kinetic pressures, will differ little from $F_1(\lambda)$ and $F_2(\lambda)$ respectively. For higher kinetic pressures, differences will increase although, as we have seen in Section 2.1.2, the sum of the dampings of the two modes must remain constant, *i.e.*

$$G_1+G_2=G_1'+G_2'=B'\quad .\quad .\qquad (10)$$

As the kinetic pressure increases there are possibilities of various types of instability occurring, depending on the way in which the pairs of coefficients G_1', H_1' and G_2', H_2' vary.

2.1.4. *The quasi-static solution for the short-period response*

If the frequency of the aircraft short-period mode is much lower than the natural frequency of the structural mode described by equation (7), then the term in D^2h in the third of equations (3) will be negligible. If, moreover, the "structure alone" mode (equation (6)) is relatively poorly damped so that the term involving Dh in (3(*iii*)) may also be neglected, then the latter equation reduces to a form from which the distortional co-ordinate h can be directly expressed in terms of w and θ and then eliminated from the first two of equations (3). In the circumstances assumed, the inertia and damping terms pertaining to the structural mode in these two equations can probably also be neglected, although this needs checking in specific cases. If the above procedure is followed, the approximate equations governing the short-period oscillation of the flexible aircraft when trimmed for level flight can be expressed in the form

$$\left.\begin{aligned}\left\{\left(1-\frac{z_{\dot w}'}{\mu_1}\right)D-z_w'\right\}w-\left\{P_1D+\left(1+\frac{z_q'}{\mu_1}\right)\right\}q&=\ z_\eta'\eta\\(\chi'D+\omega')\,w\quad+\{(1+P_2)\,D+\nu'\}\,q&=-\delta'\eta\end{aligned}\right\}\qquad (11)$$

where

$$P_1=\frac{z_hP_{\theta h}}{\mu_1(\bar f_h-f_h)},\ \text{and}\ P_2=\frac{\omega_hP_{\theta h}}{\mu_1(\bar f_h-f_h)}=-\frac{m_hP_{\theta h}}{i_B(\bar f_h-f_h)}\quad .\quad .\quad .\quad .\qquad (12)$$

$$\left.\begin{aligned}z_w'&=z_w+\frac{z_hf_w}{\bar f_h-f_h};&\qquad z_{\dot w}'&=z_{\dot w}-\frac{\mu_1P_{zh}z_h}{\bar f_h-f_h}\\z_q'&=z_q+\frac{z_h(f_q+\mu_1P_{zh})}{\bar f_h-f_h};&\qquad z_\eta'&=z_\eta+\frac{z_hf_\eta}{\bar f_h-f_h}\\\chi'&=\chi-\frac{\omega_hP_{zh}}{\bar f_h-f_h};&\qquad \omega'&=\omega+\frac{\omega_hf_w}{\bar f_h-f_h}\\\nu'&=\nu-\frac{\omega_h(f_q+\mu_1P_{zh})}{\mu_1(\bar f_h-f_h)};&\qquad \delta'&=\delta+\frac{\omega_hf_\eta}{\bar f_h-f_h}\end{aligned}\right\}\qquad (13)$$

in which

$$\omega_h=-\frac{\mu_1m_h}{i_B}.$$

The equations (11) are seen to be of the same general form as (5) which apply to the rigid aircraft, but the effective values of the aerodynamic derivatives are modified by the flexibility and inertia characteristics of the structure in accordance with equations (13) while there are modifications to the pitching inertia terms through the coefficients P_1 and P_2 defined by equations (12).

The solution of equations (11) is usually referred to as the "quasi- (or pseudo-) static" solution for the short-period response of the flexible aeroplane. This general method of dealing with the effects of structural flexibility has been referred to as the *"method of modification of derivatives"* (*see*, for instance, Section 12.6 of Duncan's text-book).

The great advantage of the "quasi-static" method is, of course, that the fourth order system of equations (3) is replaced by the second order system (11). As we have seen, application of the method is justifiable only if, in the last of equations (3),

$$\frac{P_{hh}}{\mu_1}D^2h-\frac{\bar f_h}{\mu_1}Dh$$

is negligible in comparison with $(\bar f_h-f_h)\,h$ and if the inertia and damping terms pertaining to the structural mode in the other two equations can also be neglected.

In general, the method may be expected to yield reasonably accurate results if the frequency of the short-period mode is small in relation to the lowest structural frequency involved in the problem but each case should be examined on its own merits and the orders of terms which are to be neglected should be assessed.

It may be observed that all the modified coefficients and derivatives (equations (12) and (13)) are functions of kinetic pressure in virtue of the fact that f_h is inversely proportional to that quantity. In addition, P_1, z_w', z_q', χ', ω', δ' and ν' depend on aircraft relative density μ_1 and hence on altitude (for a given weight).

2.1.5. *The problem of steady manoeuvring flight*

If we wish to study the problem of steady manoeuvring flight (flight in a vertical circle) which is the basis of the Manoeuvrability Theory developed by Gates and Lyon[19], we must put $Dw=D^2\theta=0$ as well as $D^2h=Dh=0$ in equations (3); then eliminating h as in the last section and considering the case of initially horizontal flight ($\gamma_e=0$) we obtain

$$\left.\begin{aligned} -z_w'w-\left(1+\frac{z_q'}{\mu_1}\right)q&=z_\eta'\eta \\ \omega'w\qquad\quad +\nu'q&=-\delta'\eta. \end{aligned}\right\} \quad . \qquad (14)$$

Neglecting $\frac{z_q'}{\mu_1}$, which will normally be small, and solving (14) for w, we have

$$\frac{w}{\eta}=\frac{\nu'z_\eta'-\delta'}{\omega'-\nu'z_w'} \quad . \quad . \qquad (15a)$$

or, since $\nu'z_\eta'$ will usually be small compared with δ', $\left(=-\frac{\mu_1 m_\eta'}{i_B}\right)$ at least for a tailed aircraft,

$$\frac{w}{\eta}\simeq-\frac{\delta'}{\omega'-\nu'z_w'}\simeq\frac{2m_\eta'}{AH_m} \quad . \quad . \qquad (15b)$$

where A, H_m are the lift curve slope and stick-fixed manoeuvre margin for the flexible aircraft (*cf.* form (114) of Ref. 19, remembering that $\bar{c}$ is being taken as representative length) it being assumed that $z_w'\simeq-\frac{1}{2}A$.

The lift increment ΔL corresponding to w is given by

$$\frac{\Delta L}{\eta}=A\frac{w}{\eta}\tfrac{1}{2}\rho V^2S=\frac{2m_\eta'}{H_m}\tfrac{1}{2}\rho V^2S$$
$$=-\frac{A_2\overline{V}}{H_m}\tfrac{1}{2}\rho V^2S,$$

where A_2 is the tailplane lift curve slope with respect to elevator deflection for the flexible aircraft, and $\overline{V}$ is the tail volume ratio.

Then the elevator angle per g is given by

$$Q_\eta=-\frac{\eta}{\Delta L/W}=\frac{W}{\tfrac{1}{2}\rho V^2S}\frac{H_m}{\overline{V}A_2}, \qquad (16)$$

which corresponds to form (82) of Ref. 19. The expression for the manoeuvre margin of the flexible aircraft is

$$H_m=\frac{2i_B}{\mu_1 A}(\omega'+\tfrac{1}{2}A\nu'). \quad . \quad . \qquad (17)$$

2.1.6. *Static margin and the rate of change of elevator angle to trim in rectilinear flight*

When a small change of elevator angle η is applied to produce a change of trimmed speed, the final (steady) perturbations u, w, θ and h from the initial equilibrium state are given by equations (2) with

$$Du=Dw=D^2\theta=D\theta=D^2h=Dh=0$$

i.e. by

$$\left.\begin{aligned} -x_u u-x_w w\qquad\quad +k\theta-x_h h&=0 \qquad (i)\\ -z_u u-z_w w+k\tan\gamma_e\theta-z_h h&=z_\eta\eta \qquad (ii)\\ \kappa u\ +\omega w\qquad\quad +\omega_h h&=-\delta\eta \qquad (iii)\\ -f_u u-f_w w\qquad\quad +(\bar{f}_h-f_h)h&=f_\eta\eta \qquad (iv) \end{aligned}\right\} \qquad (18)$$

Elimination of h, w and θ between the four equations (18) leads to the following relationship between u and η: —

$$\left\{z_u'-x_u'\tan\gamma_e-(z_w'-x_w'\tan\gamma_e)\frac{\kappa'}{\omega'}\right\}u$$
$$=\left\{(z_w'-x_w'\tan\gamma_e)\frac{\delta'}{\omega'}-(z_\eta'-x_\eta'\tan\gamma_e)\right\}\eta$$

where the modified derivatives z_w', z_η', ω' have already been defined by (13) and where

$$\left.\begin{aligned} z_u'&=z_u+\frac{z_h f_u}{f_h-\bar{f}_h}; \qquad \kappa'=\kappa+\frac{\omega_h f_u}{\bar{f}_h-f_h}\\ x_u'&=x_u+\frac{x_h f_u}{\bar{f}_h-f_h}; \qquad x_w'=x_w+\frac{x_h f_w}{\bar{f}_h-f_h}\\ x_\eta'&=(x_\eta)+\frac{x_h f_\eta}{\bar{f}_h-f_h},\ (x_\eta=0). \end{aligned}\right\} \quad . \qquad (19)$$

Thus the rate of change of elevator angle to trim with speed is given by

$$\frac{d\eta}{dV}=\frac{1}{V}\frac{\eta}{u}=\frac{1}{V}\cdot\frac{z_u'-x_u'\tan\gamma_e-(z_w'-x_w'\tan\gamma_e)\frac{\kappa'}{\omega'}}{(z_w'-x_w'\tan\gamma_e)\frac{\delta'}{\omega'}-(z_\eta'-x_\eta'\tan\gamma_e)}.$$

For $\gamma_e=0$ (initial equilibrium flight path horizontal) this can be reduced to the form

$$\frac{d\eta}{dV}=\frac{1}{V}\cdot\frac{m_w'z_u'-m_u'z_w'}{z_w'\left(m_\eta'-\frac{z_\eta'}{z_w'}m_w'\right)}.$$

If, further, $\left(\frac{z_\eta'}{z_w'}\right)m_w'$ is small compared with m_η' (which is normally consistent with the assumption that tail lift is negligible compared with total lift, m_w' and m_η' being of the same order)

$$\frac{d\eta}{dV}\simeq\frac{1}{Vm_\eta'}\left\{\frac{m_w'z_u'-m_u'z_w'}{z_w'}\right\}.$$

With the same assumptions, using equations (5), (7), (8) and (13) of Ref. 19, it is readily shown that the

static margin of the (flexible) aircraft can be expressed as

$$K_n = -\frac{dC_m}{dC_R} = \frac{1}{C_R} \cdot \frac{m_w' z_\eta' - m_\eta' z_w'}{-z_w'}, \qquad (20)$$

while $$m_\eta' = -\tfrac{1}{2}\bar{V} A_2,$$

so that $$\frac{d\eta}{dV} \simeq \frac{2C_R}{V} \cdot \frac{K_n}{\bar{V} A_2}, \qquad (21)$$

which is effectively the relationship (43) given in Ref. 19 for the rate of change of elevator angle with speed in terms of static margin.

2.1.7. *Control reversal and divergence*

From equation (15*a*) the condition for zero steady response to elevator deflection is

$$\nu' z_\eta' = \delta' \qquad (22a)$$

or if, as is usual with tailed aircraft, it is assumed that z_η' is negligible,

$$\delta' = 0. \qquad (22b)$$

Using (13), we may express the condition for elevator control reversal as

$$\bar{f}_h = f_h - \frac{\omega_h f_\eta}{\delta}. \qquad (23)$$

If we now write

$$\bar{f}_h = \frac{\bar{f}}{\tfrac{1}{2}\rho V^2}, \qquad (24)$$

the reversal speed V_R is given by

$$\tfrac{1}{2}\rho V_R^2 = \frac{\bar{f}}{f_h - \dfrac{\omega_h f_\eta}{\delta}}. \qquad (25)$$

There will be a real reversal speed only if

$$f_h - \frac{\omega_h f_\eta}{\delta} > 0. \qquad (26)$$

If $f_h > 0$, then $\bar{f}_h - f_h$ will vanish at a speed V_d given by

$$\tfrac{1}{2}\rho V_d^2 = \frac{\bar{f}}{f_h} \qquad (27)$$

whereupon all the modified derivatives in (13) become infinite; V_d is the divergence speed, which is real only if f_h is positive.

2.1.8. *Transfer functions for control system analysis*

In the foregoing sections we have been thinking mainly in terms of the effects of flexibility on the stability and dynamic response of the aircraft as a whole. However, for high-performance aircraft, incorporating an automatic control system, it is necessary to know the dynamic response at the location of various control system elements, over the range of frequencies to which these elements respond. In the analysis and synthesis of such systems, use is usually made of the concept of tranfer functions.

For instance, if the quasi-static equations (11), for the short period response, are solved for q/η, one such transfer function is obtained and may be expressed in the form generally adopted by servo engineers*

$$\frac{q}{\eta} = \frac{K_q(1 + T_q D)}{1 + \dfrac{2\zeta}{\omega_n} D + \dfrac{1}{\omega_n^2} D^2}, \qquad (28)$$

where the pitching velocity *gain* K_q, the *time lead constant* T_q, the *damping ratio* ζ and *natural frequency* ω_n are given as functions of the quasi-static derivatives (and hence of kinetic pressure) by the following formulae: —

$$\left.\begin{aligned}
K_q &= \frac{z_w'\delta' - \omega' z_\eta'}{\omega'\left(1 + \dfrac{z_q'}{\mu_1}\right) - \nu' z_w'} \\
T_q &= \frac{\left(1 - \dfrac{z_{\dot{w}}'}{\mu_1}\right)\delta' + \chi' z_\eta'}{\omega' z_\eta' - \delta' z_w'} \\
\omega_n^2 &= \frac{\omega'\left(1 + \dfrac{z_q'}{\mu_1}\right) - \nu' z_w'}{(1 + P_2)\left(1 - \dfrac{z_{\dot{w}}'}{\mu_1}\right) + P_1 \chi'} \\
\zeta &= \frac{\omega_n}{2}\left[\frac{\nu'\left(1 - \dfrac{z_{\dot{w}}'}{\mu_1}\right) - z_w'(1 + P_2) + \chi'\left(1 + \dfrac{z_q'}{\mu_1}\right) + P_1\omega'}{\omega'\left(1 + \dfrac{z_q'}{\mu_1}\right) - \nu' z_w'}\right]
\end{aligned}\right\} \qquad (29)$$

With the above notation, the period τ_p of the damped motion is $\tau_p = \dfrac{2\pi}{\omega_n\sqrt{(1-\zeta^2)}}$ compared with the natural period $\tau_n = \dfrac{2\pi}{\omega_n}$. Also if $\tau_{\frac{1}{2}}$ is the time to halve the amplitude

$$\tau_{\frac{1}{2}} = \frac{\log_e 2}{\zeta\omega_n}. \qquad (30)$$

or, in terms of τ_n and τ_p respectively: —

$$\left.\begin{aligned}
\frac{\tau_{\frac{1}{2}}}{\tau_n} &= \frac{\log_e 2}{2\pi\zeta} \\
\frac{\tau_{\frac{1}{2}}}{\tau_p} &= \frac{\log_e 2}{2\pi} \cdot \frac{\sqrt{(1-\zeta^2)}}{\zeta}
\end{aligned}\right\} \qquad (31)$$

Transfer functions for other response quantities may be obtained in forms similar to (28), with the identical denominator function but with numerator functions involving different gain and time constants. The general

*This form is adopted for the present discussion since it is the one used by American investigators in the reports reviewed in Section 3.2. There is, of course, no essential difference between this approach and that of aerodynamicists as exemplified, for instance, in Ref. 18 (Appendix I). In the latter approach, the operational solution for the response in q to elevator application would be written in the form

$$\frac{q}{\eta} = \frac{aD + b}{D^2 + 2RD + H},$$

from which the explicit solution, in terms of aerodynamic time τ, could be readily obtained from Ref. 22. The relationships between K_q, T_q, ζ and ω_n on the one hand, and a, b, R and H on the other are easily established.

effects of flexibility on the dynamic response of the system may be studied through its effects on the transfer function coefficients (ω_n, ζ and the gain and time constants).

It should be noted that if the frequency response of the system at frequencies near to that of a particular flexible mode is to be studied, then the effect of that mode on the motion cannot be adequately represented on a quasi-static basis; the structural mode in question must be included in the equations of motion as an additional dynamic degree of freedom and the appropriate inertial and damping terms retained. At the same time, allowance for other structural modes, whose natural frequencies fall outside the range of interest may still be made on a quasi-static basis. When structural degrees of freedom are admitted directly to the equations of motion, transfer functions become much more complicated because of the introduction of additional second order factors in both the numerator and denominator expressions.

2.2. SOME MISCELLANEOUS COMMENTS

We have seen in Section 2.1 how, starting from the general *semi-rigid* form of the equations of motion for the flexible aircraft (2), we may obtain as special cases, the sets of equations governing: —

(*i*) The dynamic response of the *rigid aircraft* (equations (1)).

(*ii*) *Short-period response* of the *flexible aircraft* (equations (3)) arising from the coupling of: —
- (*a*) The *rigid aircraft short-period mode* (equation (5)), and
- (*b*) The *"structure-alone" mode* (equation (6)).

(*iii*) The *"quasi- (pseudo-) static" solution* for the short-period response (equations (11)).

(*iv*) *Steady manoeuvring flight* (equations (14)).

(*v*) *Small changes of trim* (rectilinear flight) produced by elevator deflection.

The equations for (*iii*), (*iv*) and (*v*) are expressed in terms of *modified* (*quasi-steady*) *derivatives* (*i.e.* rigid aircraft derivatives modified to take account of flexibility on the basis of static deflections only). The use of such quasi-steady derivatives (formulae (13) and (19)) needs no justification in the case of (*iv*) and (*v*), since these are steady flight conditions. In the case of (*iii*), however, it must be emphasised that the equations of motion (11) and the modified derivatives (12) and (13) have been derived on the assumption that all inertia and damping terms, pertaining to the flexible mode(s), in the original equations of motion are negligible. The accuracy of the quasi-static solution to a particular problem will depend on the extent to which this assumption is valid.

The expressions (12) and (13) for the quasi-static modified derivatives have been derived from a semi-rigid analysis. In recent years, the semi-rigid method, as originally conceived, has been found somewhat inadequate in dealing with the steady-state aeroelastic problems of some current aircraft configurations (*see* Ref. 2, Sections 3 and 4.1). However, in circumstances where the application of the quasi-static solution of a dynamic problem is considered valid, the values of the modified derivatives may be determined by any of the alternative methods discussed in Ref. 2 or elsewhere.

It is perhaps opportune, at this juncture, to touch briefly on the question of the type of derivatives ("steady" or "unsteady") to be employed in the various sets of equations. In items (*iv*) and (*v*) the use of "steady flow" derivatives is clearly valid but the oscillations problems (*i*)—(*iii*) are essentially concerned with unsteady flow and "steady" derivatives are not strictly applicable. If, however, we consider the possible application of "unsteady" derivatives to such problems, a difficulty is encountered.

For the only "unsteady" derivatives normally available are those corresponding to simple harmonic oscillations and these are functions of frequency. Now in flutter investigations, attention is concentrated on the critical condition(s) in which undamped oscillations of a particular frequency persist in the critical mode, while other oscillatory modes are rapidly damped out; in such circumstances, the use of oscillatory derivatives appropriate to the frequency of the critical flutter mode is clearly indicated. In dynamic stability and response problems, however, the motion may be compounded of several modes which may be periodic or aperiodic; the periodic modes will usually be of widely differing frequencies and may be positively or negatively damped. Thus the usual oscillatory derivatives are not strictly appropriate to such problems and even if their use were accepted in principle, doubt would still exist as to the frequency at which they should be evaluated. At the moment, therefore, no firm recommendation can be made concerning the derivatives to be used in problems (*i*)—(*iii*).

It may be remarked, however, that at the frequencies typical of most aircraft short-period modes, the only rigid aircraft derivatives whose steady and unsteady values differ significantly*, appear to be $z_{\dot{w}}$ and $m_{\dot{w}}$ (upon which χ depends). Since the term involving $z_{\dot{w}}$ is, in any case, usually small, it would seem that in evaluating the response of the rigid aircraft, steady values may be assumed for all derivatives except $m_{\dot{w}}$, without incurring serious error. As regards the response of the flexible aircraft, it is possible that unsteady flow effects might be important for some of the derivatives of aerodynamic origin which appear in the distortional equation, but this would need investigation in particular cases.

3. Review of Literature

3.1. THEORETICAL INVESTIGATIONS

In Ref. 7, McLaughlin has investigated the effects of wing flexibility on the dynamic longitudinal stability of various aircraft configurations involving different values of three important parameters as tabulated below: —

Sweepback of wing elastic axis, $\Lambda°$	c.g. location per cent $\bar{c}$	Wing Mass / Aircraft Mass
0, 40, 60	25, 35, 45	0·15, 0·33, 0·50

*Differences are largest in the transonic range.

To represent the flexibility of the wing, a single (extra) degree of freedom, characterised by the wing-tip bending deflection h was introduced into the equations of motion which assumed a form equivalent (in American notation) to the set (3) of Section 2.1.2. The wing mode shape corresponding to h was assumed to consist of a parabolic variation of spanwise bending and a linear variation of spanwise twist, the amounts of each being proportional to h*. Steady values of the aerodynamic derivatives were used.

The period and damping of the coupled aircraft short-period and flexible wing modes were determined, as functions of kinetic pressure, by solving the semi-rigid form of the equations of motion. The solutions (which included those for the rigid aircraft, as the particular case of zero kinetic pressure) were compared with those obtained by the quasi-static method and from the structure-mode-alone equation. Results are presented in dimensional form (frequency c./sec., time to 0·1 amplitude, secs.) and in non-dimensional terms (period and reciprocal of time to damp to 0·1 amplitude, where time is expressed as fuselage lengths travelled).

From this investigation it appears that wing flexibility can appreciably affect the dynamic characteristics of an aircraft. Particular conclusions are: —

(*a*) For the swept-back configurations there is no indication of oscillatory instability due to wing flexibility. However, it appears that important changes in the character of the aircraft motion can result from the forward shift of manoeuvre point. Thus, for the most rearward centre of gravity location, the oscillation which exists at the lowest kinetic pressures quickly changes to two subsidences as the increasing kinetic pressure causes the manoeuvre point to move forward towards the centre of gravity. When the manoeuvre point becomes coincident with the centre of gravity one of the subsidences changes to a divergence, the severity of which increases as the kinetic pressure further increases. Referring to equation (9*a*), this sequence of events implies the following behaviour of the coefficients G_1', H_1' as the kinetic pressure increases: —

(*i*) $G_1' > 0$, $4H_1' > (G_1')^2$: Manoeuvre point behind c.g.; convergent oscillation.

(*ii*) $G_1' > 0$, $4H_1' = (G_1')^2$: Manoeuvre point approaches c.g.; two subsidences.

(*iii*) $G_1' > 0$, $H_1' = 0$: Manoeuvre point coincides with c.g.; one subsidence changes to a divergence.

(*iv*) $G_1' > 0$, $H_1' < 0$: Manoeuvre point ahead of c.g.; divergence increases in severity.

G_1' remains positive throughout so that there is no oscillatory instability.

For more forward centre of gravity locations, the same sequence of events occurs but at higher kinetic pressures.

The frequency and damping of the elastic wing mode (expressed in dimensional terms) both increase with kinetic pressure.

(*b*) For unswept configurations, the effects of wing flexibility are serious only for combinations of large wing-aeroplane mass ratio with forward centre of gravity locations; for these cases, the analysis indicates that the wing is subject to decrease in oscillatory stability.

(*c*) The quasi-static method appears to be fairly realistic as a means of approximating to the dynamic characteristics of swept-wing configurations. The method does not, however, appear to be accurate for unswept configurations at high kinetic pressures.

(*d*) The wing-mode-alone method gives good predictions for the characteristics of the flexible wing mode of motion for swept-wing configurations, but appears less reliable for use with unswept configurations.

It is not clear from the report why the approximate methods should work better for swept than for unswept wings.

Some effects of fuselage flexibility on static and dynamic longitudinal stability and control have been investigated by Klawans and Johnson[10]. Like McLaughlin, they start from the semi-rigid form of the equations of motion for the flexible aircraft; from these they derive the rigid, quasi-static and static-balance forms of the equations and then proceed to study: —

(*a*) Dynamic stability as described by period and damping of the fuselage and aeroplane longitudinal modes of oscillation.

(*b*) Static stability as described by longitudinal stability margins.

(*c*) Static longitudinal control as described by elevator-control deflections required for steady straight or manoeuvring flight.

The semi-rigid fuselage mode is assumed to be parabolic and the distortional co-ordinate h introduced into the equations of motion (equations (2)) is the bending deflection at the tail, non-dimensionalised with respect to wing mean chord.

Results are presented, for the most part, as graphs of characteristic quantities, relating to the various phenomena, plotted against fuselage natural frequency for various centre of gravity positions ($0{\cdot}25\bar{c}$—$0{\cdot}544\bar{c}$) and for a fixed Mach number ($M = 0{\cdot}7$) at two heights (8,000 ft. and 30,000 ft.). Quantities plotted in this way are indicated in Table I.

Further results for the aircraft short-period mode (semi-rigid solution only) are given in the form of graphs of period and time to 0·1 amplitude plotted against kinetic pressure for various values of the fuselage natural frequency at two altitudes (8,000 and 30,000 ft.) for a fixed centre of gravity position ($0{\cdot}25\bar{c}$).

The general conclusions from this investigation appear to be: —

(*i*) For fuselage stiffnesses typical of current large high-speed (subsonic) aeroplanes, fuselage flexibility appears to introduce no serious dynamic stability problems and its effects may be satisfactorily predicted by quasi-static theory.

(*ii*) For a given Mach number and altitude, the

*i.e. separate bending and torsional modes are *not* considered as would be necessary for a flutter investigation.

frequency of the aircraft mode is increased and its damping (as measured by time to 0·1 amplitude) reduced by fuselage flexibility. At the same time the frequency of the fuselage mode is decreased and its damping increased as fuselage flexibility increases. For a given fuselage stiffness (*i.e.* given natural frequency) at a particular altitude, both frequency and damping of the aircraft mode increase with increasing kinetic pressure.

Characteristics of the fuselage mode of coupled motion have not been compared with those of the fuselage-alone-mode.

(*iii*) The manoeuvre margin is increased by fuselage flexibility. If aerodynamic forces only were involved, a decrease would be expected but in steady manoeuvring flight, inertia loads acting on the distributed fuselage mass more than counteract the aerodynamic loads and a rearward shift of manoeuvre point occurs. Accordingly, greater elevator deflections are required to maintain a given manoeuvre with flexible fuselage than with rigid fuselage.

(*iv*) The effects of fuselage flexibility on the static stability margin and on the elevator angles necessary for trim in straight flight depend on the value of C_{m_0} but provided large negative values of this coefficient are avoided, undesirable effects may be prevented.

Another investigation of the effects of fuselage flexibility on dynamic stability and control has been described in Ref. 15. This concerns a projected large supersonic, high altitude aircraft of canard layout. The work included the calculation of the frequency and damping of the rigid aircraft short-period mode, the fuselage alone mode and the two modes of the combined fuselage and aircraft system, and also some response studies using a simulator. A single structural degree of freedom, corresponding to the assumption of parabolic bending of the fuselage, was admitted in the formulation of the "semi-rigid" equations of motion.

TABLE I

Phenomenon	*Quantities plotted*
Dynamic stability	Period and time to damp to 0·1 amplitude: aeroplane mode and fuselage mode.
Static stability and control for straight flight	Ratio of static - stability - margins* for flexible and rigid aircraft; elevator angle necessary for trim in straight flight.
Stability and control for steady manoeuvring flight	Ratio of manoeuvring flight stability margins† for flexible and rigid aircraft; ratio of elevator - angle - increments (flexible and rigid aircraft), necessary to maintain steady manoeuvring flight.

Results for dynamic stability were obtained from both semi-rigid and quasi-static solutions.

*Defined as $K_S = -\dfrac{\partial C_m/\partial V}{\partial C_{L_0}/\partial V}$ where C_{L_0} denotes straight-flight balance lift coefficient.

†Defined as $K_T = -\dfrac{\partial C_m/\partial z}{\partial C_L/\partial z}$

Results of the calculations are presented as graphs of frequency (c./sec.) and damping (expressed as number of cycles to half amplitude) plotted against Mach number for various altitudes. In this form, the results are not directly comparable with the American ones, but subsonically the effects of fuselage flexibility on the characteristics of the aircraft short-period mode appear to exhibit similar trends. Supersonically, however, the effects apparently change sign and the aircraft mode suffers a reduction in frequency and increase in damping. As regards the fuselage mode of coupled motion, its frequency and damping (as determined by cycles to half amplitude) are respectively greater and less than those of the fuselage-alone-mode at both subsonic and supersonic speeds. At high altitudes and high (supersonic) Mach numbers the damping of the fuselage-alone-mode is already poor so that the damping of the fuselage mode of coupled motion may become so poor as to be unacceptable.

The simulator studies were aimed at developing a rate of pitch demand control system (acting through the noseplane) to improve the damping of the aircraft. However, the results indicate that increasing the control circuit gain factor in the aircraft stabilising sense causes the fuselage mode to become less stable, and vice versa, so that the system contemplated would be unsatisfactory.

Of the group of papers issued by Vickers-Armstrongs (Aircraft) Ltd.[12, 13, 14], the first, by Hitch, is a very short note which serves as an introduction to the other two which, he points out, "illustrate the current integrated viewpoint at Vickers-Armstrongs on Aeroelastic matters and confirm the prophecies of Professor Collar"[1]. He indicates that non-flutter dynamic investigations such as those described by his colleagues[13, 14] are becoming standard practice, "are very useful in resolving the many inconsistencies which attend the simpler and more familiar approach," and "contain as special cases the following separate problems: —

(*a*) The flutter problem.
(*b*) The static aeroelastic problem.
(*c*) The "stability and control" problem.
(*d*) The conventional stressing problem."

In the investigation described in Ref. 13, eleven degrees of freedom (including vertical translation, but not pitch of the (rigid) aircraft) were allowed and a digital computer was used to solve the equations for the response of the wing and engines of the Viscount 700 Series to a vertical gust and to demonstrate the validity of simpler methods used in the design stage.

Reference 14 describes a parallel investigation into the response of the Vickers 1000 to suddenly applied elevator with particular reference to the bending stresses produced in the tailplane. A digital computer was used to solve a nine degrees of freedom problem in which the nine modes used included four structural modes, the three "rigid aircraft modes," the elevator rotation and the power control. These solutions were used to check the validity of the approximate methods commonly employed in Aerodynamic and Stress Offices. Solutions of other problems such as that of rigid aircraft stability,

tail and elevator effectiveness, and so on, were obtained by using only a selection of the nine freedoms.

Space considerations preclude a full discussion of the results of this investigation but it is clear that some of the approximate (static or quasi-static) methods of dealing with an essentially dynamic problem may involve considerable errors. Regarding longitudinal stability it is stated that the inclusion of the flexible freedoms in the problem changes considerably the frequencies of both the short-period oscillation and the phugoid without, however, affecting the rates of decay of these motions.

3.2. EXPERIMENTAL INVESTIGATIONS

Recognising the importance of aeroelastic effects on dynamic stability and control problems, particularly in regard to aircraft equipped with automatic controls, the N.A.C.A. instigated some time ago a comprehensive programme of flight tests on a B.47 (35° swept-wing) aircraft. Work performed under this programme has been described and commented on by Cole, Brown and Holleman in Refs. 8, 9, 11 and 20. The aims of the programme—to quote from Ref. 8—were "to document and analyse the airplane response to control surface motions and, through comparisons between measured and predicted response characteristics, to establish simple but adequate methods of prediction for flexible airplanes." Refs. 8 and 11, which deal respectively with longitudinal and lateral-directional response, are concerned mainly with describing the test and analytical techniques, and presenting basic data and the results of the calculations and tests. Ref. 9 represents an interim assessment and interpretation of some of the results, made before the programme was completed, while in Ref. 20, with all the results to ponder upon*, the authors seek "to bring out the important points which are sometimes overlooked in aeroelastic analyses."

The aircraft was instrumented with strain gauges, accelerometers and an optigraph as well as standard instruments so that the response of the complete aircraft could be measured. The test and analysis technique used was that of exciting the aeroplane by pulse-type motions of the controls (elevator, rudder or ailerons), measuring the transient time histories and transforming to frequency-response form by the Fourier integral. Transfer functions were then approximated from the frequency responses by a curve-fitting procedure and compared with theoretical transfer functions for the rigid aircraft and for the flexible aircraft, as determined by the quasi-static method. It may be noted that a method employing aerodynamic and structural influence coefficients was used in estimating some of the quasi-static derivatives.

The broad conclusions to be drawn from this investigation appear to be: —

(*i*) The response at frequencies appropriate to the aircraft stability modes (longitudinal short period and the Dutch roll and rolling modes) can be adequately predicted by the quasi-static method, but not from the rigid aircraft equations.

(*ii*) As the frequency increases towards that of a structural mode it is necessary to introduce a dynamic degree of freedom, corresponding to that mode, in order to predict the response accurately. Other structural modes of higher frequency may be retained as quasi-static degrees of freedom.

(*iii*) Optimum locations for control system pick-ups on, or near the node lines for the various structural modes, can be determined prior to flight. In these circumstances, the effects of flexibility can be taken entirely into account by the quasi-static method.

A particular point, with regard to the application of the quasi-static method, is stressed in Ref. 20. As the authors point out, "the application is apt to lead to false conclusions if previous concepts of rigid airplanes are retained. Terms which were formerly small become too large to be neglected. Care must be exercised to include all of the inertial terms." Referring to equations (11) to (13) this presumably means that it is important to retain the terms in P_1, P_2 and those contributions to $z_{\dot{w}}'$, $z_{\dot{q}}'$, χ' and ν' which involve P_{zh}. The authors reiterate the importance of inertial effects when discussing the behaviour of the short-period frequency of the B.47. Their investigation indicates a drop-off in frequency due to flexibility at constant Mach number; this is contrary to experience with other swept-wing aeroplanes but the apparent discrepancy may, they suggest, be attributed to the mass distribution†.

4. Discussion and Conclusions

It cannot be pretended that the foregoing review is exhaustive in regard either to the list of papers considered or to the treatment accorded to individual items in that list. Nevertheless, sufficient has been said to enable us to formulate answers to the questions posed at the end of the introduction. Before we do so, however, a few general remarks may be made.

In recent years there has clearly been, in the U.S.A., considerable activity in that sector of the Aeroelastic Domain which encompasses the problems of Aircraft Stability and Control, and some important fundamental investigations into the effects of structural flexibility on dynamic stability have been made. As far as the author is aware there has been little or no comparable work of a fundamental nature in this country, although some *ad hoc* investigations have been made by aircraft firms in connection with particular designs.

In seeking to interpret and correlate the results of the various investigations, one encounters difficulties in the form of widely differing notations, and different methods of presenting results. In particular, various authors have different ideas as to the precise quantities which most usefully describe the characteristics of an

*In fact, only the longitudinal aspects are discussed.

†As the authors have pointed out elsewhere in their report, the inertial loads act opposite to the aerodynamic loads and the final effect of flexibility will depend on the relative distribution of aerodynamic and inertial loads. It may be recalled from the discussion of the results of Ref. 10, that this relative distribution was important in determining the behaviour of the manoeuvre margin of an aircraft with flexible fuselage.

oscillatory motion and in seeking to interpret quantitatively any general qualitative statement concerning frequency or damping, one must ascertain whether the author is referring to the natural (undamped) frequency or to the actual frequency of damped oscillation, and whether his criterion of damping is the time to half (or 0·1) amplitude or the number of cycles to half (or 0·1) amplitude (given directly or in the form of the damping ratio ζ). A standardised approach in such matters would facilitate the correlation of the results of future investigations. In considering the choice of quantities to characterise an oscillation it seems useful to seek those which provide the best basis of correlation with pilots' opinions of acceptability. In this connection, an American flight investigation reported by R. P. Harper[21], suggests that short-period natural frequency ω_n and damping ratio ζ may be the best choice as regards longitudinal handling. By plotting ω_n against ζ for various conditions of an aircraft, specially modified to provide variable stability and control characteristics, Harper has been able to indicate qualitative ratings as areas of varying degree of the pilots' acceptance.

Turning now to the specific questions posed at the outset of this enquiry, we may suggest the following answers: —

(*a*) Elastic forces *do* play an important part in determining the dynamic stability characteristics of current high-performance aircraft and are likely to prove increasingly important in future supersonic designs, where, for rational design of the automatic control system, it is essential to evaluate the effects of structural flexibility on the dynamic response, over the range of frequencies to which the control-system elements respond.

(*b*) In assessing the characteristics of the aircraft modes, whose frequencies will normally fall considerably below those of the structural modes, it will usually* be satisfactory to apply the quasi-static method. In employing this method, however, care must be exercised to include appropriate inertial terms in the expressions for the modified derivatives. The "structure-alone-mode" method will usually provide a good approximation to the characteristics of the flexible mode of coupled motion.

To predict the response at frequencies in the vicinity of that of a structural mode, it is necessary to include that mode as a dynamic degree of freedom in the equations of motion but other structural modes of higher frequency may be retained as quasi-static degrees of freedom.

(*c*) We have illustrated in Section 2.1 how, starting from the semi-rigid equations of motion, the formal statement (and in some cases the solution) of various kindred aeroelastic problems may be derived. There is evidence of interest in this integrated approach both in America[10] and this country[12-14] and clearly there are considerable advantages in co-ordinating the attack on the various problems of stability and control which, hitherto, have been dealt with piecemeal. Not only should this lead to a better understanding of such problems and their interconnection, but duplication of effort in the study of overlapping aspects should be avoided.

*It will be recalled that in the theoretical investigation of the effects of wing flexibility[7] these approximate methods appeared to give unsatisfactory results for unswept wing configurations although no reason for this was apparent.

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APPENDIX

ELASTIC-INERTIA COUPLING TERMS IN THE "SEMI-RIGID" EQUATIONS OF LONGITUDINAL MOTION OF A FLEXIBLE AIRCRAFT

In the problem of longitudinal symmetric motion the only elastic displacements in which we are interested are those parallel to the z-axis. In general, if n semi-rigid modes of distortion, characterised by the distortional co-ordinates h_1, h_2, ... h_n, are allowed, then the elastic displacement δz of the element of mass at (x, y, z) in the direction of the body axis Oz will be expressible in the form

$$\delta z = \sum_{s=1}^{n} f_s(x, y)\, h_s \quad . \quad . \quad . \quad (1)$$

Following Duncan's text book (Section 12.5) we may express the components of velocity and acceleration along Oz for the element δm as

$$w' = w - qx + \sum_{s=1}^{n} \dot{h}_s f_s(x, y) \quad . \quad . \quad (2)$$

$$\gamma = \dot{w} - qV - \dot{q}x + \sum_{s=1}^{n} \ddot{h}_s f_s(x, y) \, . \quad . \quad (3)$$

The total inertia force along Oz is

$$-\sum_m \gamma \delta m = -\sum_m \left[\dot{w} - qV - \dot{q}x + \sum_{s=1}^{n} \ddot{h}_s f_s(x, y)\right] \delta m \quad (4)$$

where $\sum_m$ denotes summation over all the elements of mass.

The inertial pitching moment about the c.g. is

$$\sum_m \gamma x \delta m = \sum_m x \left[\dot{w} - qV - \dot{q}x + \sum_{s=1}^{n} \ddot{h}_s f_s(x, y)\right] \delta m. \quad (5)$$

The equation of normal forces will thus contain the set of terms

$$\sum_{s=1}^{n} \left\{\sum_m f_s(x, y)\, \delta m\right\} \ddot{h}_s \quad . \quad . \quad . \quad (6)$$

while the pitching moment equation will contain the set

$$-\sum_{s=1}^{n} \left\{\sum_m x f_s(x, y)\, \delta m\right\} \ddot{h}_s. \quad . \quad . \quad (7)$$

The longitudinal force equation will contain no such inertial terms arising from the distortion.

In formulating the dynamical equation corresponding to the co-ordinate h_r, we have to express the condition that the work done by all the forces (including inertia forces) in a virtual displacement corresponding to a small change δh_r in h_r, is zero. Now the work done by the inertia forces is

$$\delta W_I = \sum_m \gamma \delta m \delta z = \sum_m \gamma \frac{\partial z}{\partial h_r} \delta h_r \delta m$$

so that, using (3) and (1), we have

$$\frac{\partial W_I}{\partial h_r} = \sum_m \left\{\dot{w} - qV - \dot{q}x + \sum_{s=1}^{n} \ddot{h}_s f_s(x, y)\right\} f_r(x, y)\, \delta m$$

$$= (\dot{w} - qV) \sum_m f_r(x, y)\, \delta m - \dot{q} \sum_m x f_r(x, y)\, \delta m +$$

$$+ \left\{\sum_m f_r^2(x, y)\, \delta m\right\} \ddot{h}_r + \sum_{s=1}^{n}{}' \left\{\sum_m f_s(x, y) f_r(x, y)\, \delta m\right\} \ddot{h}_s \quad (8)$$

where the prime in $\sum_{s=1}^{n}{}'$ indicates that the term corresponding to $s = r$ is omitted.

Thus the dynamical equation corresponding to h_r will contain terms proportional to those on the right-hand side of (8), which may be expressed more compactly by writing

$$\left.\begin{aligned} P_{zh_r} &\equiv \frac{1}{m} \sum_m f_r(x, y)\, \delta m, \quad P_{\theta h_r} \equiv \frac{1}{m} \sum_m \frac{x}{\bar{c}} f_r(x, y)\, \delta m \\ P_{h_r h_r} &\equiv \frac{1}{m} \sum_m f_r^2(x, y)\, \delta m, \quad P_{h_r h_s} \equiv \frac{1}{m} \sum_m f_s(x, y) f_r(x, y)\, \delta m \\ &\left(= P_{h_s h_r}\right). \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (9)$$

If we now compare (8) with (6) and (7) we see that:—

(*a*) Corresponding to a term in the *normal force equation* proportional to $P_{zh_r} \ddot{h}_r$ there will be a term proportional to $P_{zh_r}(\dot{w} - qV)$ in the equation corresponding to h_r. (In the non-dimensional form of the equations (*see* equations (2) of main text) the latter term will assume the form $P_{zh_r} D(w - \theta)$.)

(*b*) Corresponding to a term in the *pitching moment equation* proportional to $-P_{\theta h_r} \ddot{h}_r$ there will be a term proportional to $-P_{\theta h_r} \dot{q}$ in the equation corresponding to h_r.

(*c*) There will be a term proportional to $P_{h_r h_r} \ddot{h}_r$ in the "h_r-equation."

(*d*) Corresponding to a term in the "h_r-equation" proportional to $P_{h_r h_s} \ddot{h}_s$, there will be a term proportional to $P_{h_r h_s} \ddot{h}_r$ in the "h_s-equation."

It may be noted that in general, a typical modal function $f_r(x, y)$ will assume non-zero values over one particular part of the aircraft structure only and will be identically zero elsewhere. Consequently some of the inertia coefficients of type $P_{h_r h_s}$, $(r \neq s)$ may vanish but $P_{h_r h_r}$ will always be non-zero.

Ninety-Fourth Annual Report of the Council 1958 - 1959

DURING the year under review the activities of the Society have increased and this trend seems likely to continue. The Council has formed Sections and Groups to cater for the more specialised interests of members since the extent of the interests of the Society, in accordance with the Charter, covers the entire field of aeronautical science and art. The name of the Guided Flight Section has been changed to the "Astronautics and Guided Flight Section" as it now embraces the wider subjects that this implies. Groups consist of smaller numbers of members having specialised interests; two are in existence, and it is likely that more will shortly be formed.

The Council has given attention during the present year to the opportunity which the Hyde Park Corner reconstruction scheme provides for the addition to 4 Hamilton Place of a lecture theatre. A satisfactory scheme has been evolved and the legal consents necessary have been obtained. The increasing demand for lectures and discussions makes it certain that such a lecture theatre will be of great value to the Society and the Council is hopeful that it will be possible shortly to proceed with the scheme. The problem of financing its construction has been carefully reviewed and the Council is likely to put the matter before the members shortly.

The Council has advised all members of the General Meeting to be held on 4th May to consider changes in the By-Laws. Attention is drawn to two of the changes proposed. The first one is the proposed By-Law affecting the Election of Fellows. It is proposed that those wishing to be considered for Fellowship complete an Application Form, which is then sent to the Council for consideration; this brings the procedure in line with that of other professional bodies. The second proposal is the inclusion of the Chairmen of each Section as *ex-officio* members of the Council, as will be the President of each Division, who will be kept more in touch with the thoughts and activities of the Society, even though he cannot attend many meetings.

During the year the members agreed to an increase in subscriptions. This was necessary to bring rising costs into balance, as the Income and Expenditure Account shows. The causes of increased costs were the general inflationary tendency which had not been countered by change of subscription for several years, the fall in advertising revenue in publications and the cost of the increase in activity mentioned earlier.

Arrangements for the Anglo-American Conference, to be held in New York in October 1959, are now well under way and the Council are hopeful that this Conference will be no less successful than its predecessors.

The President and Council wish to express their appreciation of the excellent work carried out during the year by the staff of the Society. In any learned and professional body much depends on the quality and application of the permanent staff and we have been well served.

The Council for the year 1958-1959 is as follows:-

PRESIDENT

SIR ARNOLD HALL, M.A., F.R.S., F.R.Ae.S.

PRESIDENT-ELECT

P. G. MASEFIELD, M.A.(Eng.), Hon.F.I.A.S., F.R.Ae.S.

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E. T. JONES, C.B., O.B.E., M.Eng., F.R.Ae.S.
N. E. ROWE, C.B.E., D.I.C., B.Sc., F.C.G.I., M.I.Mech.E., F.I.A.S., F.R.Ae.S.

VICE-PRESIDENTS

E. S. MOULT, C.B.E., Ph.D., B.Sc.(Eng.), M.I.Mech.E., F.R.Ae.S.
AIR MARSHAL SIR OWEN JONES, K.B.E., C.B., A.F.C., B.A., D.I.C., M.I.Mech.E., F.R.Ae.S.
AIR COMMODORE F. R. BANKS, C.B., O.B.E., M.I.Mech.E., Hon.F.I.A.S., F.R.Ae.S.

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SIR SYDNEY CAMM, C.B.E., F.R.Ae.S.
PROFESSOR A. R. COLLAR, M.A., D.Sc., F.I.A.S., F.R.Ae.S.
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W. TYE, O.B.E., B.Sc., F.R.Ae.S.
T. A. WOLSTENHOLME, A.R.Ae.S.

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Secretary: A. M. BALLANTYNE, T.D., B.Sc.(Eng.), Ph.D., Hon.F.C.A.I., F.I.A.S., F.R.Ae.S.

Election of Officers of the Society

PRESIDENT OF THE SOCIETY, 1958-1959

SIR ARNOLD A. HALL, M.A., F.R.S., F.R.Ae.S., President of the Society for the year 1958-1959, took office at the Annual General Meeting of the Society held on Thursday 8th May 1958.

PRESIDENT-ELECT

MR. P. G. MASEFIELD, M.A.(Eng.), Hon.F.I.A.S., F.R.Ae.S., Vice-President of the Society, was elected the President-Elect of the Society for 1959-1960, and takes office as President in May 1959.

VICE-PRESIDENTS

The following were elected Vice-Presidents of the Society for 1958-1959:—

E. S. MOULT, C.B.E., Ph.D., B.Sc.(Eng.), M.I.Mech.E., F.R.Ae.S.
AIR MARSHAL SIR OWEN JONES, K.B.E., C.B., A.F.C., B.A., D.I.C., M.I.Mech.E., F.R.Ae.S.
AIR COMMODORE F. R. BANKS, C.B., O.B.E., M.I.Mech.E., Hon.F.I.A.S., F.R.Ae.S.

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MR. S. SCOTT HALL
MR. W. TYE
MR. L. A. WINGFIELD (*Solicitor*)
*MR. B. S. SHENSTONE
*DR. G. S. HISLOP

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*MR. A. E. WOODWARD-NUTT
*MR. G. G. ROBERTS

**Denotes a non-Council Member.*

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Executive Committee of the National Physical Laboratory	Sir William Farren
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Institution of Electrical Engineers	
Committee on Regulations for the Electrical Equipment of Aircraft	Mr. C. G. A. Woodford
Committee on Radio Equipment for Civil Aircraft	Mr. J. M. Furnival
Code Drafting Committee on the Proposed Code of Practice on the Measurement and Abatement of Radio Interference in Aircraft	Mr. J. M. Furnival
British Conference on Automation and Computation: Group B —Computation and Automatic Control Group	Professor E. J. Richards
Institution of Mechanical Engineers	
British Conference on Automation and Computation: Engineering Applications Group	Professor E. J. Richards Dr. A. M. Ballantyne
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Units and Symbols Standards Committee USM/-	Dr. A. M. Ballantyne
Abbreviations and Symbols Committee USM/2	Miss E. C. Pike
Man-Powered Aircraft Committee	Mr. S. Scott Hall

Annual General Meeting

The 93rd Annual General Meeting of the Society was held on Thursday 8th May 1958, in the Offices of the Society, with Sir George Edwards, President, in the Chair. The Report of the Council for the year and the Accounts for 1957-58 were before the assembled Members and were adopted unanimously.

The President reported the following elections to fill the vacancies on the Council:—

*Air Commodore F. R. Banks, C.B., O.B.E. (*Fellow*)
*Sir Sydney Camm, C.B.E. (*Fellow*)
*H. H. Gardner (*Fellow*)
*Air Marshal Sir Owen Jones, K.B.E., C.B., A.F.C. (*Fellow*)
Squadron Leader R. C. G. T. Rogers (*Associate Fellow*)
W. Tye, O.B.E. (*Fellow*)
T. A. Wolstenholme (*Associate*)

*Re-elected to Council.

The Secretary read the names of those elected to Fellowship:—

Dr. Edward George Bowen
Mr. Stanley Edward Clotworthy
Air Chief Marshal Sir Ralph Alexander Cochrane
Mr. Frederick George Ronald Cook
Mr. George Francis Hemsley
Mr. Ronald Hills
Monsieur Maurice Louis Hurel
Dr. Robin Ralph Jamison
Mr. John Owen Napier Lawrence
Mr. Gordon Roy McGregor
Dr. Kurt Werner Mangler
Mr. Reginald John Monaghan
Mr. Sydney MacDonald Parker
Mr. George Brian Gibbon Potter
Professor Elliott Gray Reid
Dr. John Seddon
Mr. Ronald Andrew Shaw
Mr. Frederick Nicholas Slingsby
Mr. Frank Tyson
Mr. Robert Herbert Whitby
Professor George Alan Whitfield

The President presented the following Prizes:

Simms Gold Medal	Mr. L. F. Nicholson
The George Taylor (of Australia) Gold Medal	Mr. R. L. Lickley and Mr. L. P. Twiss
The Edward Busk Memorial Prize	Dr. D. Küchemann
The Orville Wright Prize	Professor A. R. Collar
The Herbert Ackroyd Stuart Memorial Prize	Dr. R. R. Jamison
The J. E. Hodgson Prize	Professor H. J. van der Maas
The Branch Prize	Mr. M. B. Morgan
The Navigation Prize	Mr. W. Makinson and Mr. G. M. Hellings
The Usborne Memorial Prize	Mr. D. G. Drake

Sir George Edwards then handed over the Badge of Office of President to his successor, Sir Arnold Hall.

Named Lectures

The Wilbur Wright Memorial Lecture

The 46th Wilbur Wright Memorial Lecture was given by Dr. (now Sir) George Gardner, C.B., F.R.Ae.S., on "Automatic Flight—The British Story" on Thursday 15th May 1958. A full report was published in the July 1958 Journal.

The British Commonwealth Lecture

The Fourteenth British Commonwealth Lecture was delivered on Thursday 9th October 1958 by Mr. J. C. Floyd, F.C.A.I., M.I.A.S., F.R.Ae.S., on "Some Aspects of Canadian All-Weather Fighter Development." A full report was published in the December 1958 Journal.

The Lanchester Memorial Lecture

The Second Lanchester Memorial Lecture was delivered by Professor A. R. Collar, F.I.A.S., F.R.Ae.S., on "Aeroelasticity—Retrospect and Prospect" on Thursday 20th November 1958. A full report was published in the January 1959 Journal.

The Louis Bleriot Lecture

The Twelfth Louis Bleriot Lecture was delivered in London by Monsieur l'Ingénieur Géneral de l'Air Noel Daum on "The Griffon and the Prospect of Combining the Turbo-Ram-Jet Engine for Propulsion of Aeroplanes at High Speed" on Thursday 12th March 1959. A full report will be published in the Journal.

Lectures

The following Lectures have been read before the Society in 1958/59.

1958

Monday 27th October: LECTURE*—The Bloodhound, D. J. Farrar, F.R.Ae.S.
Tuesday 4th November: LECTURE—The Spectre Rocket Engine, W. N. Neat, A.F.R.Ae.S.
Friday 7th November: JOINT LECTURE WITH THE HELICOPTER ASSOCIATION—Development of the Fairey Rotodyne, Dr. G. S. Hislop, F.R.Ae.S.
Tuesday 11th November: LECTURE—Boundary Layer Control to Produce High Lift at Low Speeds, Dr. J. Williams, A.F.R.Ae.S.
Monday 24th November: LECTURE*—Inertia Guidance, J. E. Pateman.
Thursday 4th December: MAIN LECTURE AT BIRMINGHAM BRANCH—Freighters; A General Survey, E. D. Keen, F.R.Ae.S.
Tuesday 9th December: LECTURE—Application of a Constant Frequency A.C. Electrical System to Aircraft and Missiles, S. S. Hall and A. Thomas.
Monday 15th December: ALL DAY DISCUSSION ON HYPERSONIC FLOW.
Monday 15th December: LECTURE*—Drone Aircraft, H. G. Conway, F.R.Ae.S.
Thursday 18th December: MAIN LECTURE—Air Traffic Control Over the North Atlantic, E. W. Pike.

1959

Tuesday 6th January: YOUNG PEOPLE'S LECTURE—Rocket Flight in Space, Dr. L. R. Shepherd.
Thursday 8th January: MAIN LECTURE—Safe Mechanisms, R. Hafner, F.R.Ae.S.
Tuesday 13th January: LECTURE—Stress Corrosion—The Engineer's View, P. H. Wall, A.F.R.Ae.S.
Tuesday 27th January: LECTURE—Some Aspects of the Engine Noise Problem, P. Lloyd, C.B.E., A.F.R.Ae.S.
Thursday 5th February: FIRST HALFORD LECTURE, F. B. HALFORD—AT THE HATFIELD BRANCH—J. L. P. Brodie, F.R.Ae.S.
Thursday 12th February: MAIN LECTURE*—Earth Satellites, W. H. Stephens, F.R.Ae.S.
Tuesday 17th February: LECTURE—Engine Starting Systems, R. H. Woodall, F.R.Ae.S.
Thursday 19th February: LECTURE*—Theoretical Studies of Guided Missile Systems, E. G. C. Burt.
Tuesday 24th February: LECTURE—The Flight Development of an Aircraft Before and During its Operation, Dr. A. E. Russell, F.R.Ae.S.; C. Abell, F.R.Ae.S. and P. F. Green.
Tuesday 3rd March: INFORMAL DISCUSSION—Rocket Propulsion—Liquid and Solid. Introduced by A. V. Cleaver and Dr. G. P. Sillitto. For Members of the Astronautics and Guided Flight Section and Graduates of the Society.
Thursday 5th March: FIRST FAIREY MEMORIAL LECTURE, SIR RICHARD FAIREY—AN APPRECIATION—AT LONDON AIRPORT BRANCH—G. W. Hall, F.R.Ae.S.
Tuesday 10th March: LECTURE—Water and Ice in the Atmosphere, R. F. Jones.

Thursday 19th March: LECTURE*—Long Range Missiles, E. C. Cornford, A.F.R.Ae.S.

The following Lectures will complete the Programme:

Thursday 9th April: MAIN LECTURE—AT THE PRESTON BRANCH—The Art of Developing Aero Engines, A. C. Lovesey, F.R.Ae.S.

Tuesday 21st April: ALL DAY DISCUSSION ON THE STRUCTURAL EFFECTS OF KINETIC HEATING.

Monday 27th April: LECTURE*—Basic Principles of Radar with Particular Reference to Aircraft and Missile Applications, F. D. Boardman, M.A.

Tuesday 5th May: LECTURE—The Potential Use of Aircraft for Agricultural Purposes (with particular reference to New Zealand), R. H. Scott.

Thursday 14th May: 47TH WILBUR WRIGHT MEMORIAL LECTURE—Managing Aviation Technologies, C. J. McCarthy.

*Lectures and Main Lectures marked * have been arranged by the Committee of the Astronautics and Guided Flight Section.*

Presidential Reception 1959

The President, Sir Arnold Hall, and Lady Hall, supported by Miss Caroline Hall, received some four hundred members and guests at a Reception held in the home of the Society, 4 Hamilton Place, W.1., on 13th February 1959. During the evening Sir Arnold addressed the members through the medium of a closed-circuit television. Sir Arnold's talk was published in the March 1959 JOURNAL.

First International Congress of the Aeronautical Sciences

The Society participated in the First Congress which was held in Madrid from 8th-13th September 1958, and this Congress proved an excellent start to the Series. A report was published in the December 1958 JOURNAL.

The Second Congress is planned for September 1960 in Zurich, and details will be announced in the JOURNAL when they are available.

Garden Party, 22nd June 1958

The Garden Party was held on Sunday 22nd June at White Waltham Aerodrome (by kind permission of the Air Ministry and The Fairey Aviation Company). A Report was published in the JOURNAL for December 1958.

Fourth Air Transport Course 31st March-21st April 1959

The Fourth Air Transport Course will be held at Oriel College, Oxford, from 31st March to 21st April 1959. Forty-four Students have enrolled for the Fourth Course, demonstrating that the demand for such a Course has not lessened. This is the greatest number to enrol in any one Course; the previous numbers have been thirty-four, thirty-six and thirty-four, and by the end of the present course almost one-hundred-and-fifty students will have benefited from the instruction given during their residence at Oxford.

Much of the success of the Courses has been due to the high quality of the Lectures, and the Council thanks all the Lecturers for their assistance; in particular the Council appreciates the work of the Resident Lecturers.

Astronautics and Guided Flight Section

The Section Committee for 1958/59 was announced at the Annual General Meeting of the Section which was held on 16th September 1958, and was as follows:—

Sir George Gardner (*Chairman*)	Mr. D. J. Farrar
Mr. A. D. Baxter	Mr. H. H. Gardner
Mr. A. V. Cleaver	Mr. S. Scott Hall
Mr. J. E. P. Dunning	Mr. W. H. Stephens

Mr. J. D. Duncan was later co-opted as a representative of the Graduates' and Students' Section.

A Report of the Annual General Meeting was published in the December 1958 JOURNAL.

At the Council Meeting held on 15th January 1959, it was decided that the Section should be known in future as the Astronautics and Guided Flight Section.

The Committee arranged lectures and discussions, enumerated in the Lecture Programme, and these have been very well attended. For every lecture there has been a heavy demand for visitors' tickets; so great has been this demand that the visitors' tickets have had to be limited.

The Council wishes to record its appreciation of the work of Sir George Gardner and the Committee in arranging an attractive lecture programme.

Although visitors have been welcome, it is hoped that many of those who have availed themselves of the privilege of visitors' tickets will become members of the Society.

Graduates' and Students' Section

In the year 1958-9 the Graduates' and Students' Committee organised nine lectures, nine visits, two film shows and two dances. In addition, it has reviewed a range of matters affecting the interests of Graduates and Students.

Lectures and Visits

Average attendance at lectures and film shows during the year was 49. In the first half of the year there was a falling-off in attendance at lectures; in an attempt to offset this and to encourage social mingling of members, the Committee arranged for free coffee and biscuits to be provided at lectures and paid for out of the Section's funds. As a result of this—or possibly because of a more attractive lecture programme—lecture attendances rose in the autumn. Three of the Section's lectures were reported in the technical press during the year, and one was reported in the national newspapers.

Visits during the year were arranged to research establishments, aircraft companies, airports, car manufacturers and a newspaper. As in the past, most visits were well attended and in several cases were heavily oversubscribed. The average attendance was 20.

Dances

The Committee arranged two dances, on 13th June and 28th November 1958. Both were very successful and the total attendance at the two was 382. This year the Committee introduced a standard charge of 7s. a head for its dances; this included food and wine, beer and soft drinks. By arranging for refreshments to be produced by Committee members and their wives or girl-friends and drink to be served by volunteer barmen, costs have been kept to a minimum.

Other Activities

The Section's page in the JOURNAL is used to keep members in touch with Section activities, as well as for publishing reports of lectures and visits.

During the year the Committee was asked to appoint a Graduate representative to the committee of the Astronautics and Guided Flight Section. Mr. J. D. Duncan was appointed and also co-opted as a member of the Section's Committee.

With a view to keeping distant members in touch with the Section's activities, the Committee asked for volunteers who would represent it in their own areas. Ten members were appointed; they are resident in Birkenhead, Luton, Greenwich, Swindon, Coventry, Glasgow, Manchester, Oxford, Derby and London (Cricklewood). It is also worthy of note that two Committee members live in Southampton and Brough respectively, and that the Brough member is on the Committee of the local R.Ae.S. branch. The representative at Glasgow is the Secretary of the recently formed local Graduates' and Students' Section, and the Derby representative is a member of the Derby Branch Committee.

The Section's Committee has prepared a memorandum on the activities of the Society; this has been considered by the Future Policy Committee, and some of the suggestions are being examined.

Finally, the Committee wishes to thank all those who have given lectures and arranged visits on its behalf. It also wants to thank the members of the Society's staff who have helped the Committee in its work.

Committee Members

J. R. Cownie (Grad.) *Chairman*
P. D. Stewart (Grad.) *Hon. Secretary*
M. P. Laker (Grad.) *Treasurer*
G. E. Deadman (Grad.) *Lectures Secretary*
A. R. M. Pickering (Stud.) *Visits Secretary*
P. T. Ross (Grad.) *Hon. Editor*
J. D. Duncan (Grad.)
J. Gibbins (Stud.)
C. Jones (Stud.)
Sqn. Ldr. R. C. G. T. Rogers (A.F.)
N. E. Rowe (Fellow)
B. N. Tomlinson (Stud.)
W. G. Wilson (Grad.)

Lectures and Film Shows

1958

6th March: The Electronic Digital Computer by W. F. M. Payne.

25th March: Annual General Meeting and Film Show.

18th April: The Rôle of Independent Airlines in British Air Transport Development by A. M. Blakemore.

5th May: Future Trends in Naval Air Operations by Capt. O. M. Bailey.

25th September: The Next Generation of Civil Aircraft by G. H. Lee.

16th October: The Fatigue of Aircraft by Major P. L. Teed.

29th October: Film Show.

11th November: The Air Transport Auxiliary by Sir Gerard d'Erlanger.

9th December: The Future of the British Aircraft Industry by E. C. Bowyer.

1959

14th January: To Do With Selling the Viscount by D. J. Lambert.

25th February: Deck-landing of High-speed Naval Aircraft by Lt. Cdr. D. J. Whitehead.

Visits

1958

31st May: B.O.A.C. Engineering Base, London Airport.

25th June: Royal Aircraft Establishment, Farnborough.

16th July: Gatwick Airport.

22nd August: de Havilland Aircraft Co. Ltd., Hatfield.

19th September: *Daily Telegraph*.

28th November: National Physical Laboratory.

6th December: Cooper Motors Ltd.

20th December: Handley Page, Ltd.

1959

21st January: Vauxhall Motors Ltd.

Groups

The Council has agreed to the formation of Groups within the Society; these will cover the smaller specialised fields of members and also specialised activities of the Society. The rules governing such Groups were enumerated in the December 1958 JOURNAL.

HISTORIC AIRCRAFT MAINTENANCE GROUP

An excellent response was received from members to an appeal for volunteers to help to maintain the aircraft of the Nash Collection, which are now housed at Hendon. The Historic Aircraft Maintenance Group has been formed in conjunction with the Society of Licensed Aircraft Engineers. About sixty volunteers from both Societies have been grouped into teams, each of which has been given one of the aircraft to survey, overhaul and repair where necessary.

The concern of the Maintenance Group is the *preservation* rather than the *renovation* of the aircraft. Work started at Hendon in September and is now in progress on all the aircraft, but it is rather hampered by the inadequate accommodation now available at Hendon. Nevertheless the Council is grateful for the help which has been received from the Air Ministry in providing a roof over the Collection and is particularly grateful to the Officers Commanding R.A.F. Station Hendon and No. 71 Maintenance Unit, Bicester, for doing everything they can to help in this work.

There have been several meetings to discuss the future of the Collection which, it is hoped, will form part of a National Aeronautical Museum.

MAN-POWERED AIRCRAFT GROUP

The Council has approved the formation of a Man-Powered Aircraft Group; the first meetings of the Group will be held in the session 1959-60. Any member wishing to join the Group should write to the Secretary for further particulars.

Discussions are at present being held regarding the formation of other groups.

Membership

The Membership of the Society has now reached 10,540 and has continued to increase at an encouraging rate in 1958. There has been a slight easing of the upward trend but the number of new members showed no significant drop over those of 1957. There were 899 new members, a fall of only 25 compared with last year. On the debit side, the losses in 1958 due to resignations and terminations were 272. This figure should be compared with 203 in 1956 and 237 in 1957.

The easing in the rate of increase of membership slight though it is, is largely due to the recent re-adjustment in the Aircraft Industry since many who have resigned have given as their reason the fact that they have left the Industry.

As hitherto, the principal increase is in the class of Associate Fellows. There were 190 new entries compared with 175 last year. The figure for Associates was almost the same as before, at 192, while new Graduates dropped from 144 to 135 and Students fell from 394 to 364.

On the year's figures it can be taken that the Society is maintaining its drive for more members and that despite difficulties in the Industry, membership has not suffered to any great extent. The table on page 245 shows the membership figures as at 31st December 1958.

Officers and Committees

The Council wish to thank all members of the various Committees, who have made a large contribution to the work of the Society. This opportunity is taken to acknowledge the arduous work of the *Ad Hoc* Committee on By-Laws under the Chairmanship of Mr. A. V. Cleaver. The work of his Committee has been exacting, but the results are now before the members for their consideration.

Divisions

The Divisions in Australia, New Zealand and Southern Africa are maintaining their activities. In Southern Africa, Branches are being formed in Durban and Salis-

MEMBERSHIP AT 31st DECEMBER 1958

Grade	London Register	Australian Division	Southern Africa Division	New Zealand Division	Life and Honorary	Totals	Suspended London Register Members (Included in the foregoing figures)	1958 Elected Members not yet paid
Fellows ..	444 (434)	16 (15)	2 (3)	4 (4)	28 (H) (30) 18 (L) (18)	512 (504)	4 (3)	— (—)
Associate Fellows ..	4403 (4042)	180 (155)	64 (55)	40 (34)	17 (L) (18)	4704 (4304)	93 (83)	24 (10)
Associates ..	2190 (2119)	90 (77)	98 (89)	67 (66)	5 (L) (5)	2450 (2356)	104 (84)	9 (8)
Graduates ..	1145 (1186)	41 (55)	4 (5)	2 (5)	— (—)	1192 (1251)	45 (44)	8 (6)
Students ..	1362 (1222)	46 (48)	9 (5)	4 (5)	— (—)	1421 (1280)	99 (72)	19 (46)
Founder Members ..	9 (12)	— (—)	— (—)	— (—)	1 (L) (1)	10 (13)	— (—)	— (—)
Companions ..	170 (163)	8 (10)	6 (5)	3 (3)	6 (H) (4) 7 (L) (7)	200 (192)	8 (4)	1 (4)
Temporary Honorary Members ..	— (—)	— (—)	— (—)	— (—)	53 (H) (53)	53 (53)	— (—)	— (—)
	9723 (9178)	381 (360)	183 (162)	120 (117)	87 (H) 87 (H) 48 (L) 49 (L)	10,542 (9953)	353 (290)	61 (74)

Figures in brackets are corresponding figures at 31st December 1957.

bury. The Hon. B. J. Schoeman, Minister of the Union of South Africa has become Honorary President of the Division.

Mr. M. M. Waghorn, President of the Australian Division, on the invitation of the President, has attended a Meeting of the Council of the Society.

Several members of the Society, resident in the United Kingdom, have visited the Divisions and have been very pleased at the welcome which has been given them by the members of the Division. The Secretaries of the Divisions in turn have expressed their appreciation of the talks and lectures given by visiting members and have repeated their wish to meet members of the Society who visit the Dominions.

Branches

The number of Branches is now twenty-eight. The President and members of the Council have been impressed by the enthusiasm of the Branch Officers, who urge on the work of the Society. To the work of the Secretaries much of the success is due, and the Council appreciates this and wishes to acknowledge the debt owed to the many Secretaries, with their Chairmen and Committees.

The number of Candidates for the N. E. Rowe Medals has been disappointing: the Branches are aware of this and are applying much thought to this problem.

Twice a year a Conference of Branch Secretaries has been held in London; in April 1959, this Conference will be held in Bristol, at the invitation of the Bristol Branch.

During the year two additional commemorative lectures have been founded at Branches, the Halford Lecture at Hatfield and the Fairey Lecture at the London Airport Branch. These were well attended and should prove outstanding features of the Branch Lecture Programmes.

The only Branch overseas, Singapore, continues to be active; again members visiting Singapore are requested to inform the Secretary so that they may learn, first hand, of the activities of this Branch and assist them in adding variety to their programme.

The Glasgow Branch of the Society has formed a Graduates' and Students' Section which is being organised by a "steering" Committee of eight members under the Chairmanship of Dr. A. W. Babister, A.F.R.Ae.S., Chairman of the Branch. Honorary Secretary of the Section is Gordon H. K. Goold, Grad.R.Ae.S. An interesting programme of lectures and visits has been arranged for the Section and an enthusiastic response is expected from Glasgow University, the Technical Colleges and Industry.

The Chester Branch held an Aeronautical Show and Garden Party on 31st May. A report was published in JOURNAL for August 1958.

Medals and Awards of the Society

Full particulars of the Medals and Awards of the Society were published in the June and July 1958 JOURNALS.

Honorary Fellow

The Council has pleasure in recording that SIR RICHARD SOUTHWELL, M.A., L.L.D., D.Sc., D.Eng., F.R.S., Hon.F.I.A.S., F.R.Ae.S. was accorded the honour of Honorary Fellow of the Society.

Honorary Companion

The Council has pleasure in recording that MR. W. E. NIXON, F.C.I.S., one of the original "D.H." team, Chairman of de Havilland Holdings and of the Aircraft and Propeller Companies and a Director of all the other de Havilland Companies, was accorded Honorary Companionship of the Society.

The Council has pleasure in recording also that MR. GUSTAVUS GREEN has been accorded Honorary Companionship of the Society for his work on the design and development of the early Green engines. The scroll of Honorary Companionship was presented to Mr. Green by the President, Sir Arnold Hall, before the Council meeting on 15th January 1959.

HENLOW CADET PRIZE

The Council, at a recent Meeting, agreed to establish a Royal Aeronautical Society Prize for the Cadet, at R.A.F. Henlow, who obtains the best aggregate of marks in the final year Higher National Diploma assessed examination subjects. The Prize takes the form of Graduate Membership of the Society for three years without payment of subscription or entrance fee. In addition, a book

is presented to the successful Cadet to commemorate the award.

The first award of the Prize, for 1957/58, was made to PILOT OFFICER M. S. MALPASS. The Prize for 1958/9 was awarded to PILOT OFFICER A. J. LOWERY.

ELLIOTT MEMORIAL PRIZE

The Elliott Memorial Prize, presented to the Apprentice receiving the highest marks in the General Studies Examination at Halton R.A.F. Station, has been awarded to the following:—

Corporal Apprentice R. J. Soppitt
Sergeant Apprentice Perry
Sergeant Apprentice Pirie
Warrant Officer Apprentice R. B. Thomson

ROYAL AERONAUTICAL SOCIETY PRIZES IN AERONAUTICS

The Society's Prizes in Aeronautics, awarded annually to the best student in the Aeronautical Department at Universities and Colleges organising courses in aeronautics, have been awarded for 1958 as follows:—

University of Bristol—Joint Award: A. G. Fraser and D. H. Lloyd
Cambridge University: R. A. Sawyer
Glasgow University: D. B. Gemmell
Imperial College, London: Colin Wood
Queen Mary College, London: J. F. A. Nash
Southampton University: J. A. Wilson
College of Aeronautics, Cranfield: A. G. J. Baker.

SCHOLARSHIPS

The Charter Scholarship: J. A. Wilson.
The Geoffrey de Havilland Memorial Scholarship: A. J. W. Smith.

GRANTS FROM THE EDUCATION FUND

Grants in aid of further study and research in aeronautics have been awarded to the following:—

J. M. Moten
R. W. Roberts

(*Note*: The EDWARD BUSK STUDENTSHIP IN AERONAUTICS was not awarded this year.)

Honours Awarded to Members

Members of the Society have been honoured by Her Majesty the Queen during the year. These the Council have much pleasure in congratulating.

Other Honours have been conferred upon Members of the Society by learned Societies and other bodies; the Council also congratulates these Members.

BIRTHDAY HONOURS LIST 1958

C.B.
M. B. Morgan (*Fellow*)

C.B.E.
Dr. E. S. Moult (*Fellow*)
Group Captain S. W. Lane (*Associate Fellow*)

O.B.E.
L. Haworth (*Associate Fellow*)

M.B.E.
Squadron Leader J. W. Whitelegg (*Associate Fellow*)

Queen's Commendation for Valuable Service in the Air
Squadron Leader J. S. Booth (*Associate*) (Deceased)
G. L. Howitt (*Associate*)

M.V.O.
J. R. Finnimore (*Associate Fellow*)

NEW YEAR'S HONOURS LIST 1959

K.B.E.
Dr. G. W. H. Gardner (*Fellow*)

C.B.
Air Vice-Marshal G. Silyn Roberts (*Fellow*)

C.M.G.
S. F. Follett (*Fellow*)

C.B.E.
S. E. Clotworthy (*Fellow*)
Group Captain S. C. Pope (*Associate Fellow*)
R. H. Schlotel (*Fellow*)

O.B.E.
Thomas Bancroft (*Associate Fellow*)
D. J. Farrar (*Fellow*)
Major P. L. Teed (*Fellow*)
Group Captain A. S. Knowles (*Associate Fellow*)

OTHER HONOURS AWARDED TO MEMBERS

The 1957 Award of the Louis Breguet Trophy has been made to Raoul Hafner (*Fellow*), Chief Designer (Helicopters), Bristol Aircraft Ltd., for his achievements, "many and of great value," in the helicopter world.

A Paul Tissandier Diploma was awarded to F. N. Slingsby (*Fellow*) by the Federation Aeronautique Internationale.

Honorary Fellowship of the Institute of the Aeronautical Sciences was conferred on Sir George Edwards (*Fellow*), Immediate Past-President of the Royal Aeronautical Society and Managing Director, Vickers-Armstrongs (Aircraft) Ltd.

His Excellency Mr. John Hay Whitney, The American Ambassador, presented the following Honours to Members of the Society on behalf of the President of the United States of America:

L. Boddington, C.B.E. (*Fellow*), Medal of Freedom (Co-Inventor of the Angled Deck).
Dennis Lean (*Associate Fellow*), Medal of Freedom (Co-Inventor Mirror of Sight).
C. C. Mitchell, O.B.E. (*Associate Fellow*), Medal of Freedom, for his invention of the Steam Catapult.

Dr. Theodore von Kármán (*Honorary Fellow*) was awarded a Timoshenko Medal by the American Society of Mechanical Engineers for "his contribution to the mechanics of fluids and solids, particularly those leading to major advancements in aeronautics."

Sir Geoffrey Taylor (*Honorary Fellow*) was awarded a Timoshenko Medal by the American Society of Mechanical Engineers for outstanding work in the technical field of applied mechanics. He has also been awarded the Modesto Panetti Prize of the Turin Academy of Sciences for his work on aerodynamics. Sir Geoffrey was formerly Yarrow Research Professor of the Royal Society.

Dr. Hugh L. Dryden (*Honorary Fellow*) was awarded the Rice Memorial Medal by the American Ordnance Association for contributions in missile work. Dr. Dryden is Deputy Director of N.A.S.A.

Donations

Donations, which are most gratefully acknowledged, have been received during 1958 from the following:

Blackburn and General Aircraft Company Limited
Bristol Aeroplane Company Limited
de Havilland Holdings Limited
Dowty Equipment Limited
English Electric Group
Folland Aircraft Limited
Hawker Siddeley Group
Hunting Aircraft Limited
Rolls-Royce Limited
Society of British Aircraft Constructors
Vickers-Armstrongs (Aircraft) Limited
Westland Aircraft Limited

The Society has also received grants for Technical Work from:—

The Society of British Aircraft Constructors
The Ministry of Supply

Associate Fellowship Examinations

The Associate Fellowship Examinations were held in June and December 1958 at home and overseas. The Council wishes to record their thanks to the Examiners for their co-operation and to those who organised the arrangements for the overseas examinations.

Library

Loans again showed an increase of 30 (1,491) on the previous year, but acquisitions by the library dropped from 337 to 309. The drop was due to purchases and presentations since review copies increased from 145 to 175. A record was kept, for the first time, of the number of reports received, which numbered 713. The information service continues to be busy and each year a wider public becomes aware of the library's facilities.

Many calls are received from firms' librarians for material which they are unable to purchase but which the Society acquires through a combination of status and goodwill. Relations with similar bodies in foreign countries are most cordial and it is noteworthy that several American Librarians have made a point of visiting the library while on short visits to Europe.

In exchange for the JOURNAL a quite considerable number of Journals are received from Iron Curtain countries.

Several gifts of relics have been received during the year and these have been announced, as received, in the JOURNAL.

Publications

The circulation of the JOURNAL continues to rise as the membership increases and with still more outside subscriptions from all over the world, the number of copies printed in January 1959 was 11,700—600 more than in January 1958. Altogether 3,034 copies of the JOURNAL go abroad each month to 78 different countries. A break-down of the circulation of the JOURNAL has recently been undertaken and has shown that there are few places in the world with any interest in aeronautics, which do not receive the JOURNAL.

The widening scope of the Society's lecture programme, together with the greater number of papers submitted, has inevitably meant longer delays in publication and as space is, of necessity, limited, standards are being tightened and other steps taken to ensure that delays in publication are reduced as much as possible, there is not quite such a time lag, at present, with technical notes. Seven more lectures were published in 1958 than in 1957, including four given before the Guided Flight Section. During the past few months a number of papers have been submitted from the United States of America.

The practice of giving brief descriptions of all the Additions to the Library, introduced in January 1958, seems to be useful and authoritative reviews of the more important books are being published more quickly. Offers of reports for inclusion in the Report Section have been received from new sources abroad.

THE PROCEEDINGS OF THE 1957 HIGH ALTITUDE AND SATELLITE ROCKETS SYMPOSIUM have been published; they have been well reviewed.

THE PROCEEDINGS OF THE SIXTH ANGLO-AMERICAN CONFERENCE are expected to be ready during the next two months.

The reprinting of the first fifteen volumes of the JOURNAL (1897-1911) by Peter Murray Hill (Publishers) Ltd., was completed towards the end of 1958. These volumes, together with the reprinted ANNUAL REPORTS of the Society (1866-1893) by the same firm, are an invaluable record of the beginnings of aeronautics. The original editions have been out of print for a number of years—only 300 copies of the first issues of the JOURNAL were published—so the reprinted volumes mean that libraries and other organisations have an opportunity to complete their sets.

The Society has given University Microfilms Ltd. permission to record on microfilm both the JOURNAL and the AERONAUTICAL QUARTERLY in complete volumes; these will be available only to those already subscribing to the JOURNAL and the QUARTERLY. The first volumes, 1959, will be available early in 1960, but it is hoped that preceding volumes will be microfilmed later.

The Journal and Publications Committee is now considering the compilation of a comprehensive subject-author index for all the Society's publications since 1866. This is a tremendous undertaking and will probably have to be produced in a number of parts over the next few years.

The Society's ever-increasing amount of printed material has made steadily more difficult the work of combining responsibility for editorial work and advertisements for the JOURNAL and the Council has appointed Magazine Advertising Ltd., as its contractor for advertisements for the JOURNAL as from 1st January 1959.

Much credit is again owed to the Society's printers who continue to give invaluable co-operation and service.

The AERONAUTICAL QUARTERLY continues to strengthen its position as the leading British aeronautical research journal. Through the Editorial Board's policy of increasing the size of each issue to about 100 pages, the time lag between receipt of a paper and publication has been kept down to an acceptable level of eight to nine months. The applications for subscriptions to the QUARTERLY continue to increase steadily. The field of subjects covered has widened and there has been an increase in the number of papers published on aircraft propulsion. There is still room for more papers on the "allied sciences"" for example metallurgy and meteorology, and these would be welcomed by the Editorial Board.

As in previous years, the Council is most grateful to the Editorial Referees of the AERONAUTICAL QUARTERLY, whose willing and conscientious work not only ensures the high standard of published papers but very often stimulates the authors in their current and future work.

THE MONOGRAPHS AND TEXTBOOKS well fulfil the purpose for which they were designed, that of closing gaps in the literature, and they do this with benefit to the Society. *Landing Gear Design*, by H. G. Conway, was published in March 1958 and *Aircraft Electrical Engineering*, edited by G. G. Wakefield, in March 1959. As increased commercial publication leaves fewer gaps, so the need for such form of publication by the Society decreases, and activities in this field are tending to diminish.

Technical

The past year has seen several major projects of the Society's Technical Department brought to fruition. In addition there has been a considerable extension of the group of organisations making use of the Society's Technical work, together with a corresponding increase in revenue. The overall influence and effect of the work was discussed by the President in his Address to the Society (*c.f.* March JOURNAL, pp. 129-134) and requires no further comment. The major projects completed were the issue of the first Volume of Fatigue Data sheets and the completion of Volume I of a Material Properties Handbook, in co-operation with the Advisory Group for Aeronautical Research and Development (A.G.A.R.D.). However, of equal importance to the provision of data in completely new fields is the maintenance and extension of the well-established work on Structures, Aerodynamics and Performance, and this has continued steadily.

Twenty-nine new and revised Structures Data Sheets were circulated to subscribers and dealt, in the main, with the buckling of parallelogram and triangular panels, the revision and extension of data on flat panels in shear, the buckling of unstiffened circular cylindrical shells and the extension of data on stress concentration effects. Among new topics reviewed during 1958 and on which work is

(*continued on p.* 262)

THE ROYAL

(INCORPORATED

BALANCE SHEET

1957 Figures £		£ s. d.	£ s. d.	£ s. d.
	CURRENT LIABILITIES			
8297	Sundry Creditors		9867 6 3	
5022	Subscriptions and other amounts received in advance		5818 5 10	
				15685 12 1
	SURPLUS (subject to depreciation of Investments)			
	Reserve for Conferences and Courses			
	Balance at 31st December 1957		2812 19 1	
	Add transfer from Income and Expenditure Account		1000 0 0	
			3812 19 1	
	Add Receipts less expenditure during year		124 18 1	
2813			3937 17 2	
	Income and Expenditure Account			
	Balance at 31st December 1957	18280 10 10		
	Less Excess of Expenditure over Income for year to date	6068 0 8		
			12212 10 2	
18280				16150 7 4
£34412				£31835 19 5

A. A. HALL
President.

G. P. BULMAN
Honorary Treasurer.

REPORT OF THE AUDITORS TO THE MEMBERS

In our opinion the above balance sheet and the annexed income and Society Endowment Fund included in the annexed accounts of Aeronautical Trusts Ltd., and of its deficiency for the year ended on that date.

We have obtained all the information and explanations which we considered in agreement with them and the said information and explanations.

3 Frederick's Place, Old Jewry, London, E.C.2.
20th March 1959.

AERONAUTICAL SOCIETY

BY ROYAL CHARTER 1949)

31st DECEMBER 1958

1957 Figures £		£ s. d.	£ s. d.
	CURRENT ASSETS		
1	Stock of Journals and other publications	1 0 0	
15693	Sundry debtors and payments in advance	13460 16 2	
7029	Balances at Bank and Cash in Hand	6508 18 8	
			19970 14 10
5600	INVESTMENTS AT COST Market value 31st December 1958 £4,474 (1957 £4,175)		5600 0 0
	AERONAUTICAL TRUSTS LIMITED		
1	21 shares of 1/- each fully paid at cost	1 1 0	
683	Amounts due on current account	859 3 7	
			860 4 7
	PRINTED BOOKS, BINDINGS, OLD PRINTS, ETC.		
50	At nominal amount		50 0 0
	COLLECTION OF HISTORICAL AIRCRAFT (including Nash Collection)		
5355	At cost		5355 0 0
£34412			£31835 19 5

OF THE ROYAL AERONAUTICAL SOCIETY

expenditure account of the Society, together with the accounts of the Royal Aeronautical
give a true and fair view of the state of the Society's affairs as at 31st December 1958,

necessary. In our opinion the Society has kept proper books, and the said accounts are

(*Signed*) PRICE WATERHOUSE & CO.

THE ROYAL

INCOME AND EXPENDITURE ACCOUNT

1957 Figures £			£ s. d.	£ s. d.
		ESTABLISHMENT EXPENSES		
2883		Ground Rent, Heating, Lighting, Insurance and Repairs		2863 18 9
		ADMINISTRATIVE AND OFFICE EXPENSES		
13294		Salaries, Wages and National Insurance	15322 19 8	
1334		Pension and Pension Premiums	2140 11 4	
2740		Printing and Stationery	2251 3 10	
1977		Postages and Telephone	2519 3 11	
321		Travelling	286 3 7	
486		Office Furniture and Equipment	780 1 4	
486		Other Charges	759 18 1	
	20638			24060 1 9
		JOURNAL AND PUBLICATIONS		
4658		Salaries and Pension Premiums	4724 15 7	
21275		Printing	22293 7 9	
676		Printing Year Book	350 0 0	
3409		Postages and Wrappers	4246 18 5	
1093		Other Expenses	1607 8 1	
	31111			33222 9 10
		TECHNICAL COMMITTEES		
6890		Salaries and Pension Premiums	7681 12 2	
4632		Printing and other charges	4945 3 8	
187		Travelling Expenses	307 1 6	
	11709			12933 17 4
		GARDEN PARTY		
	2477	Expenses		2402 12 8
	745	EXAMINATIONS EXPENSES		802 8 4
	703	MEETINGS		1739 16 4
	1500	RESERVE FOR CONFERENCES AND COURSES		1000 0 0
	612	DINNERS AND RECEPTIONS		739 13 4
		LIBRARY		
1335		Salaries and Pension Premiums	1701 15 11	
623		Expenses	522 10 4	
	1958			2224 6 3
	—	NASH COLLECTION MAINTENANCE EXPENSES *less* DONATION		71 6 7
	605	GRANTS TO BRANCHES AND SECTIONS		690 0 0
	269	PRIZES AND AWARDS		219 10 0
	300	CHARTER SCHOLARSHIPS		300 0 0
	870	LEGAL AND PROFESSIONAL CHARGES		503 12 6
	372	*Payment to Canadian Aeronautical Institute*		— — —
	1250	*Surplus of Income over Expenditure for Year*		— — —
	£78002			£83773 13 8

AERONAUTICAL SOCIETY

FOR THE YEAR ENDED 31st DECEMBER 1958

1957 Figures £			£ s. d.	£ s. d.
29531		MEMBERS' SUBSCRIPTIONS		31488 18 11
11011		DONATIONS AND GRANTS		10510 17 7
		INTEREST AND DIVIDENDS		
168		Interest on Investments (Gross)	168 0 0	
248		Interest on Deposit Account at Bank	237 4 7	
5466		Surplus on Endowment Fund Income and Expenditure Account for the year	5772 11 7	
	5882			6177 16 2
		JOURNAL AND PUBLICATIONS		
14452		Advertising Revenue	11277 11 11	
10967		Sales	11309 1 5	
	25419			22586 13 4
		TECHNICAL COMMITTEES		
3618		Sales		4750 3 6
		GARDEN PARTY		
1649		Sale of Tickets	1300 16 3	
372		Profit on Programme	426 12 0	
	2021			1727 8 3
520		EXAMINATIONS FEES		463 15 3
—		BALANCE BEING EXCESS OF EXPENDITURE OVER INCOME FOR YEAR CARRIED TO BALANCE SHEET		6068 0 8
£78002				£83773 13 8

BALANCE SHEET

1957 Figures £		£ s. d.	£ s. d.
	SHARE CAPITAL		
	AUTHORISED: 40 shares of 1s. each	2 0 0	
1	ISSUED: 21 shares of 1s. each fully paid		1 1 0
	ROYAL AERONAUTICAL SOCIETY ENDOWMENT FUND		
	CAPITAL ACCOUNT		
136566	Balance at 31st December 1957	137820 15 8	
1253	*Add* Entrance Fees received during year	1173 18 0	
1	Donations received during year	26 16 0	
137820		139021 9 8	
	INCOME ACCOUNT		
9104	Balance as at 31st December 1957	9103 14 6	
146924			148125 4 2
	ROYAL AERONAUTICAL SOCIETY EDUCATION FUND		
	INCOME ACCOUNT		
485	Balance at 31st December 1957	523 16 11	
39	*Add* Surplus of Income over Expenditure for year to date ..	204 18 2	
524			728 15 1
	EDWARD BUSK STUDENTSHIP IN AERONAUTICS		
	CAPITAL ACCOUNT		
5424	Balance as at 31st December 1957		5423 10 4
	GEOFFREY DE HAVILLAND MEMORIAL FUND		
	CAPITAL ACCOUNT		
4176	Balance at 31st December 1957	4215 17 5	
40	*Add* Donation received during year	21 0 0	
4216			4236 17 5
£157089	*Forward*		£158515 8 0

TRUSTS LIMITED

31st DECEMBER 1958

1957 Figures £		£ s. d.	£ s. d.	£ s. d.
1	CASH IN HAND			1 1 0
	ROYAL AERONAUTICAL SOCIETY ENDOWMENT FUND			
	Leasehold Property at cost *less* amounts written off			
	4, 8 and 9 Hamilton Place			
	At cost	14185 1 9		
	Less Amortisation written off to date	11056 1 9		
3784			3129 0 0	
	Furniture at cost *less* depreciation			
	At cost	6396 1 11		
	Less Depreciation written off to date	4863 17 8		
1852			1532 4 3	
134232	Investments at cost		143722 15 2	
	Market values 31st December 1958 £123,067 (1957 £100,303)			
	Current Assets			
1301	Sundry Debtors		375 0 0	
6255	Balance at Bank		225 8 4	
			148984 7 9	
(–500)	*Less* Amount due to the Royal Aeronautical Society		859 3 7	
146924				148125 4 2
	ROYAL AERONAUTICAL SOCIETY EDUCATION FUND			
392	Investment at cost		602 5 11	
	Market value 31st December 1958 £630 (1957 £395)			
24	*Amount due from Edward Busk Studentship in Aeronautics*		— — —	
108	Balance at bank		126 9 2	
524				728 15 1
	EDWARD BUSK STUDENTSHIP IN AERONAUTICS			
4807	Investments at valuation 31st December 1951		4806 10 0	
601	Investments at cost		601 6 6	
			5407 16 6	
	Market value 31st December 1958 £4,655 (1957 £4,435)			
40	Balance at bank		15 13 10	
(–24)	*Less Amount due to the Royal Aeronautical Society*		— — —	
5424				5423 10 4
	GEOFFREY DE HAVILLAND MEMORIAL FUND			
	Investment at cost		4226 2 2	
4176	Market value 31st December 1958 £3,083 (1957 £2,851)			
40	Balance at Bank		10 15 3	
4216				4236 17 5
£157089	*Forward*			£158515 8 0

BALANCE SHEET—*Continued*

1957 Figures £		£ s. d.	£ s. d.	£ s. d.
157089	*Forward*			158515 8 0
	WILBUR WRIGHT MEMORIAL FUND			
	CAPITAL ACCOUNT			
2212	As at 31st December 1957	.. ..	2211 17 11	
	INCOME ACCOUNT			
155	Balance at 31st December 1957	135 19 2		
(–19)	*Less* Excess of Expenditure over Income for year to date	19 1 8	116 17 6	
2348				2328 15 5
	EDWARD BUSK MEMORIAL FUND			
	CAPITAL ACCOUNT			
449	As at 31st December 1957	449 6 1		
—	*Add* bequest from Estate of the late Lt.-Col. Mervyn J. P. O'Gorman	1000 0 0	1449 6 1	
	INCOME ACCOUNT			
253	Balance at 31st December 1957	256 16 11		
4	*Add* Surplus of Income over Expenditure for the year to date	3 10 4	260 7 3	
706				1709 13 4
	PILCHER MEMORIAL FUND			
	CAPITAL ACCOUNT			
100	As at 31st December 1957	.. ..	99 14 0	
	INCOME ACCOUNT			
75	Balance at 31st December 1957	80 10 8		
5	*Add* Income for year to date	5 7 4	85 18 0	
180				185 12 0
	USBORNE MEMORIAL FUND			
	CAPITAL ACCOUNT			
109	As at 31st December 1957	.. ..	109 2 5	
	INCOME ACCOUNT			
76	Balance at 31st December 1957	71 12 4		
(–4)	*Less* Excess of Expenditure over Income for year to date	4 10 8	67 1 8	
181				176 4 1
	HERBERT ACKROYD STUART FUND			
	CAPITAL ACCOUNT			
691	As at 31st December 1957	.. ..	691 9 0	
	INCOME ACCOUNT			
727	Balance at 31st December 1957	750 17 10		
24	*Add* Surplus of Income over Expenditure for year to date	24 0 6	774 18 4	
1442				1466 7 4
	R.38 MEMORIAL FUND			
	CAPITAL ACCOUNT			
982	As at 31st December 1957	.. ..	981 13 10	
	INCOME ACCOUNT			
1217	Balance at 31st December 1957	1286 14 1		
70	*Add* Income for year to date	69 11 8	1356 5 9	
2269				2337 19 7
164215	*Forward*			£166719 19 9

TRUSTS LIMITED

31st DECEMBER 1958

1957 Figures £		£ s. d.	£ s. d.
157089	*Forward*		158515 8 0
	WILBUR WRIGHT MEMORIAL FUND		
2251	Investments at cost	2286 11 3	
	Market value 31st December 1958 £1,797 (1957 £1,662)		
197	Balance at Bank	42 4 2	
(–100)	*Less Amount due to the Royal Aeronautical Society*	— — —	
2348			2328 15 5
	EDWARD BUSK MEMORIAL FUND		
658	Investments at cost	690 0 6	
	Market value 31st December 1958 £525 (1957 £461)		
69	Balance at Bank	1019 12 10	
(–21)	*Less Amount due to the Royal Aeronautical Society*	— — —	
706			1709 13 4
	PILCHER MEMORIAL FUND		
156	Investments at cost	170 13 8	
	Market value 31st December 1958 £116 (1957 £97)		
24	Balance at Bank	14 18 4	
180			185 12 0
	USBORNE MEMORIAL FUND		
174	Investments at cost	174 11 1	
	Market value 31st December 1958 £114 (1957 £109)		
17	Balance at Bank	1 13 0	
(–10)	*Less Amount due to the Royal Aeronautical Society*	— — —	
181			176 4 1
	HERBERT ACKROYD STUART FUND		
1278	Investments at cost	1428 5 10	
	Market value 31st December 1958 £1,018 (1957 £822)		
185	Balance at Bank	38 1 6	
(–21)	*Less Amount due to the Royal Aeronautical Society*	— — —	
1442			1466 7 4
	R.38 MEMORIAL FUND		
2005	Investments at cost	2302 17 3	
	Market value 31st December 1958 £1,638 (1957 £1,269)		
264	Balance at Bank	35 2 4	
2269			2337 19 7
164215	*Forward*		£166719 19 9

BALANCE SHEET—*Continued*

1957 Figures £		£ s. d.	£ s. d.	£ s. d.
164215	*Forward*			166719 19 9
	SIMMS GOLD MEDAL FUND			
	CAPITAL ACCOUNT			
528	As at 31st December 1957		527 15 9	
	INCOME ACCOUNT			
135	Balance at 31st December 1957	134 8 3		
	Less Excess of Expenditure over Income for year			
(–1)	to date	4 8	134 3 7	
662				661 19 4
	ALSTON MEMORIAL FUND			
	CAPITAL ACCOUNT			
251	As at 31st December 1957		250 8 10	
	INCOME ACCOUNT			
86	Balance at 31st December 1957	87 10 7		
	Less Excess of Expenditure over Income for year			
1	to date	16 5 0	71 5 7	
338				321 14 5
£165215				£167703 13 6

REPORT OF THE AUDITORS TO THE

In our opinion the foregoing accounts give a true and fair view of the state and of the surplus of the Funds for the year ended on that date.

We have obtained all the information and explanations which we considered which are in agreement with them and with the said information and explanations, give

3 Frederick's Place, Old Jewry, London, E.C.2.
20th March 1959.

TRUSTS LIMITED

31st DECEMBER 1958

1957 Figures £		£ s. d.	£ s. d.
164215	*Forward*		166719 19 9
	SIMMS GOLD MEDAL FUND		
585	Investments at cost	648 10 1	
	Market value 31st December 1958 £492 (1957 £404)		
97	Balance at Bank	13 9 3	
(–20)	*Less Amount due to the Royal Aeronautical Society*	— — —	
662			661 19 4
	ALSTON MEMORIAL FUND		
295	Investments at cost	316 7 6	
	Market value 31st December 1958 £232 (1957 £201)		
53	Balance at Bank	5 6 11	
(–10)	*Less Amount due to the Royal Aeronautical Society*	— — —	
338			321 14 5
£165215			£167703 13 6

MEMBERS OF AERONAUTICAL TRUSTS LTD.

of the Company's affairs and of the Funds administered by it as at 31st December 1958,

necessary. In our opinion the Company has kept proper books, and the said accounts, in the prescribed manner the information required by the Companies Act, 1948.

(*Signed*) PRICE WATERHOUSE & CO.

INCOME AND EXPENDITURE ACCOUNTS

ROYAL AERONAUTICAL SOCIETY

1957 Figures £		£ s. d.
655	Amortisation of Leasehold Property	655 0 0
320	Depreciation of Furniture	319 15 9
10	Legal Expenses	10 10 0
5466	Surplus of Income over Expenditure for year, transferred to the Royal Aeronautical Society	5772 11 7
£6451		£6757 17 4

ROYAL AERONAUTICAL SOCIETY

£		£ s. d.
608	Grants made in 1958	457 10 0
39	Surplus of Income over Expenditure for year, carried to Balance Sheet	204 18 2
£647		£662 8 2

EDWARD BUSK STUDENTSHIP

£225	Transfer to Royal Aeronautical Society Education Fund	£225 7 0

GEOFFREY DE HAVILLAND

£121	Transfer to Royal Aeronautical Society Education Fund	£121 6 2

WILBUR WRIGHT

£		£ s. d.
100	1958 Lecture Premium	100 0 0
£100		£100 0 0

EDWARD BUSK

£		£ s. d.
21	1958 Award	21 0 0
4	Surplus of Income over Expenditure for year, carried to Balance Sheet	3 10 4
£25		£24 10 4

TRUSTS LIMITED

FOR THE YEAR ENDED 31st DECEMBER 1958

ENDOWMENT FUND

1957 Figures £		£ s. d.
2617	Interest on Investments (Gross)	2617 1 4
1407	Interest on Investments (*less* Tax)	1580 6 10
—	Interest on Deposit Account at Bank (Gross)	66 12 8
927	Refund of Income Tax	993 16 6
1500	Rents Receivable	1500 0 0
£6451		£6757 17 4

EDUCATION FUND

£		
—	Interest on Investments (Gross)	10 0 0
—	Interest on Investments (*less* Tax)	5 15 0
300	Contribution from Royal Aeronautical Society (Charter Scholarship)	300 0 0
226	Transfer from Edward Busk Studentship in Aeronautics	225 7 0
121	Transfer from Geoffrey de Havilland Memorial Fund	121 6 2
£647		£662 8 2

IN AERONAUTICS

£225	Interest on Investments (Gross)	£225 7 0

MEMORIAL FUND

£121	Interest on Investment (Gross)	£121 6 2

MEMORIAL FUND

£		£ s. d.
81	Interest on Investments (Gross)	80 18 4
19	Excess of Expenditure over Income for year, carried to Balance Sheet	19 1 8
£100		£100 0 0

MEMORIAL FUND

£		£ s. d.
25	Interest on Investments (Gross)	24 10 4
£25		£24 10 4

INCOME AND EXPENDITURE ACCOUNTS

PILCHER

1957 Figures		
£5	Income for year, carried to Balance Sheet	£5 7 4

USBORNE

1957 Figures		
£		£ s. d.
10	1958 Award	10 10 0
£10		£10 10 0

HERBERT ACKROYD

1957 Figures		
£		£ s. d.
21	1958 Award	21 0 0
24	Surplus of Income over Expenditure for year, carried to Balance Sheet	24 0 6
£45		£45 0 6

R.38

1957 Figures		
£70	Income for year, carried to Balance Sheet	£69 11 8

SIMMS GOLD

1957 Figures		
£		£ s. d.
20	1958 Award	20 0 0
£20		£20 0 0

ALSTON

1957 Figures		
£		£ s. d.
10	1958 Award	2 8 0
—	Cost of striking die for Medal	25 0 0
1	*Surplus of Income over Expenditure for year, carried to Balance Sheet*	— — —
£11		£27 8 0

TRUSTS LIMITED

FOR THE YEAR ENDED 31st DECEMBER 1958—*Continued*

MEMORIAL FUND

1957 Figures		£ s. d.
£5	Interest on Investments (Gross)	£5 7 4

MEMORIAL FUND

£		£ s. d.
6	Interest on Investment (Gross)	5 19 4
4	Excess of Expenditure over Income for year, carried to Balance Sheet	4 10 8
£10		£10 10 0

STUART FUND

£		£ s. d.
45	Interest on Investments (Gross)	45 0 6
£45		£45 0 6

MEMORIAL FUND

£70	Interest on Investments (Gross)	£69 11 8

MEDAL FUND

£		£ s. d.
19	Interest on Investments (Gross)	19 15 4
1	Excess of Expenditure over Income for year, carried to Balance Sheet	4 8
£20		£20 0 0

MEMORIAL FUND

£		£ s. d.
11	Interest on Investment (Gross)	11 3 0
—	Excess of Expenditure over Income for year, carried to Balance Sheet	16 5 0
£11		£27 8 0

currently proceeding are optimum compression structures, extension of data on sandwich panels, local crippling of formed sections and buckling of unstiffened or ring stiffened cylindrical shells in bending. These are problems which have been indicated as being of particular importance in relation to the design of the present generation of high speed civil aircraft; it is also noteworthy that the work on the buckling of unstiffened shells also relates to some of the problems encountered in missile design.

A new supplementary issue of Aerodynamics Data Sheets was completed at the end of the year and was issued early in 1959. It consisted of ten sheets, some of them running to many pages, which made a considerable extension to data already issued on forces and moments on bodies at supersonic speeds and also presented data on lift curve slope of wing-body combinations at transonic and supersonic speeds, ground effect on lift and drag and flow fields around subsonic jets in a parallel stream. Work is now proceeding on real gas effects, transonic area rule, downwash at supersonic and subsonic speeds and buffet boundaries. Most of the information issued during 1958, and that on which work is currently proceeding has application to operational conditions ranging from the take-off phase of a civil air liner to the re-entry phase of an extra-atmospheric vehicle.

Closely related to the work on Aerodynamics is the work on Performance, which, during 1958, entered the final stages of renewed activity. The final stage has been marked by the near completion of a group of data sheets on optimum climb techniques for a range of missions and the estimation of turning performance and rolling manoeuvrability. Data sheets on these subjects are scheduled for issue in the early summer of 1959, meanwhile work is continuing on position and calibration error corrections to indicated Mach number and air speed and estimation of approach speed nad landing distance. These are all problems which have been indicated by appropriate authorities as being of interest in the design, evaluation and operation of aircraft of all speed ranges under present-day high traffic density conditions.

Another important aid to the design and operation of aircraft has been provided by the issue of the first volume of Fatigue Data Sheets. In addition to important introductory information on principles of design and reference literature, correlated numerical data is presented on gust frequencies, endurances of joints and complete wings, the effect of mean stress on test pieces and stress concentration effects. Although this first issue can only be regarded as marking the beginning of the series, and leaves much still to be covered, it has been extremely well received not only for use in aircraft applications but also by those interested in nuclear plant, automobiles, shipping and miscellaneous mechanical products. Problems at present under intensive review for further data sheets include basic statistical concepts and methods, effect of interference in bolted joints, the capacities of testing machines and fatigue of bolts.

Volume I of the *Materials Properties Handbook* was completed by the Technical Department for publication by AGARD in August 1958. This first volume gives chemical, physical, static strength, fatigue and elevated temperature properties of those aluminium alloys in most common use in Canada, France, Italy, the United Kingdom and the United States. Like the Society's Data Sheets the Handbook allows for revision and amendment and new and revised sections are at present in preparation. Work is now well advanced on a second volume relating to steels.

The success of these activities is largely due to the guidance and monitoring of the work of the Technical Staff provided by the expert Technical Committees. These Committees are constituted as follows:

Structures Committee

H. B. Howard (*Chairman*)	E. D. Keen
H. L. Cox	E. Loveless
Professor W. S. Hemp	Dr. E. H. Mansfield
D. James	F. Tyson

Aerodynamics Committee

Professor A. D. Young (*Chairman*)	H. Metcalfe
R. Dickson	J. D. Poole
J. W. Fozard	R. A. Shaw
Dr. D. W. Holder	H. H. B. M. Thomas
R. Melling	A. K. Weaver

Performance Committee

R. H. Whitby (*Chairman*)	G. E. Rogerson
D. G. Brown	J. C. Stevenson
J. R. Collingbourne	C. F. Toms
R. P. Dickinson	A. H. Yates
S. R. Hughes	

Fatigue Committee

H. L. Cox (*Chairman*)	H. B. Howard
R. J. Atkinson	N. H. Mason
K. E. Cheverton	R. H. Sandifer
A. J. Fenner	J. K. Williams
G. Forrest	

Members of the Technical Department have represented the Society at three of the panel meetings of AGARD during 1958 and the Head of the Department, Mr. A. J. Barrett, has continued to represent the Society as a member of the Structures and Materials Panel. Comprehensive accounts of these meetings were prepared for the Technical Committees and circulated to a large number of technical contacts among the Society's membership. The Department has continued to assist in the answering of a wide range of queries from members and others and with the organisation of several of the Society's technical discussions and meetings.

Obituaries 1958

The Council regrets to record the death of the following members of the Society during 1958:—

A. R. I. Austin (*Student*)
R. M. Balston (*Founder Member*)
J. P. Booth (*Associate Fellow*)
J. S. Booth (*Associate*)
The Hon. A. R. Boyle (*Associate Fellow*)
Major F. H. Bramwell (*Fellow*)
P. F. Bryan (*Associate Fellow*)
A. B. Carr (*Associate Fellow*)
J. E. Chorlton (*Associate Fellow*)
M. H. Cook (*Associate*)
P. Coyle (*Associate*)
A. F. Cressall (*Associate Fellow*)
J. J. Davies (*Associate Fellow*)
Major G. Dennison (*Founder Member*)
Prof. W. F. Durand (*Fellow*)
C. W. George (*Associate Fellow*)
E. E. Gardiner (*Associate*)
L. M. Hilton (*Associate Fellow*)
D. W. Howe (*Associate*)
Major H-M. Jullerot (*Fellow*)
H. A. Krasinski (*Associate Fellow*)
R. Leach (*Associate Fellow*)
J. A. McCulloch (*Associate Fellow*)
W. O. Manning (*Fellow*)
W. E. M. Miller (*Associate Fellow*)
Lt. Col. M. O'Gorman (*Honorary Fellow*)
G. P. Olley (*Associate*)
N. R. Parry (*Associate*)
J. J. C. Reid (*Associate*)
N. Ring (*Associate Fellow*)
W. C. S. Roberts (*Associate*)
J. D. Russell (*Associate*)
W. P. Savage (*Fellow*)
H. D. Strawson (*Associate Fellow*)
F. S. Turner (*Associate*)
Sir Alliott Verdon-Roe (*Honorary Fellow*)
L. H. G. Walford (*Founder Member*)
E. P. Warner (*Honorary Fellow*)
D. R. Willey (*Student*)

TECHNICAL NOTES

On the Importance of Engine Pressure Level to Turbo-Jet Engine Reheat Performance

by
W. A. WOODS, Ph.D.
(Rolls-Royce Ltd., Derby)

IN THIS NOTE the reheat thrust boost for a turbo-jet engine is shown to depend upon various dimensionless parameters, one of which is engine pressure level. The importance of this ratio is illustrated graphically and it is shown to be most important over the range normally encountered on a test bed. It is shown that a given reheat system would deliver a higher thrust boost on a high pressure level engine than it would on a low pressure level engine. Finally, the pressure level effect on the thrust from an engine having a reheat system fitted but operating with the reheat unlit is discussed.

NOTATION

- A effective area of throat of nozzle
- M rate of flow through nozzle (weight per unit time)
- P total pressure in the nozzle
- p_0 ambient pressure around the nozzle
- T temperature
- X thrust
- γ ratio of specific heats for the gas passing through the nozzle

$\gamma_E = 1{\cdot}33$

$\gamma_R = 1{\cdot}29$

Suffixes

- E non-reheat engine nozzle
- R reheat nozzle
- U nozzle in the reheat system fitted but unlit
- p reheat pipe

THEORY

By considering one-dimensional, isentropic, steady flow, the thrust from a choked, convergent nozzle is shown in the Appendix to be,

$$X = \left[2\left(\frac{2}{\gamma+1}\right)^{\frac{1}{\gamma-1}} \frac{P}{p_0} - 1 \right] A p_0 \quad . \quad . \quad (1)$$

When a reheat system is fitted to a turbo-jet engine it is customary to operate the engine in the same manner as a non-reheat engine is operated. That is, the compressor would operate on the same working line, and pressures and temperatures throughout the engine would be the same in the "reheat fitted" case as in the non-reheat case. To achieve this condition a two (or more) position nozzle is fitted to cater for (*a*) the reheat lit case, and, (*b*) the reheat unlit case. The engine is said to be "restored" to the non-reheat condition and, accordingly, the total pressure at the exit from the turbine is the same in all cases.

PRESSURE DROP THROUGH A REHEAT SYSTEM

The drop of pressure through a reheat system may be regarded as being made up of two parts:—

(*i*) the throttling loss caused by turbulence around the flame stabilisers, and

(*ii*) the fundamental heating pressure loss.

The first may be regarded as a fixed proportion of the total pressure. The magnitude of this pressure drop depends upon the flame stabiliser geometry and the Mach number of the flow in the pipe.

The proportion of the total pressure loss caused by heating depends approximately upon the Mach number in the pipe and the ratio of reheat temperature to engine jet pipe temperature (T_R/T_E).

The ratio of the total pressures in reheat and non-reheat nozzles is given by the following equation,

$$\frac{P_R}{P_E} = f\left\{ \begin{matrix} \text{Mach numoer} \\ \text{in pipe,} \end{matrix} \begin{matrix} \text{Flame} \\ \text{stabiliser} \\ \text{geometry,} \end{matrix} \left(\frac{T_R}{T_E}\right) \right\} \quad (2)$$

where the suffix R denotes reheat nozzle and suffix E denotes non-reheat engine nozzle. P is the total pressure in the nozzle and f denotes a "function of."

If the reheat nozzle is choked, it may be shown that[1]:—

$$\frac{M_R (T_R)^{\frac{1}{2}}}{P_E A_E} = Q_{R\,\max} = f(\gamma_R) \quad . \quad . \quad (3(a))$$

and for the non-reheat engine with a choked nozzle

$$\frac{M_E (T_E)^{\frac{1}{2}}}{P_E A_E} = Q_{E\,\max.} = f(\gamma_E) \quad . \quad . \quad (3(b))$$

where M is the rate of flow through the nozzle (weight per unit time). From equations 3(*a*) and (*b*):—

$$\frac{P_R}{P_E} = \frac{M_R}{M_E}\left(\frac{T_R}{T_E}\right)^{\frac{1}{2}} \frac{Q_{E\,\max.}}{Q_{R\,\max.}} \frac{A_E}{A_R} .$$

As the parameter $Q_{\max.}$ is not very sensitive to changes in γ and if there are no great changes in T_E and T_R then $Q_{E\,\max.}$ and $Q_{R\,\max.}$ will be constants, thus:—

$$\frac{P_R}{P_E} = \text{constant} \times \frac{M_R}{M_E}\left(\frac{T_R}{T_E}\right)^{\frac{1}{2}} \frac{A_E}{A_R} .$$

Further, as there are no great changes in T_E and T_R the ratio $\frac{M_R}{M_E}$ will also be constant, and therefore:—

$$\frac{P_R}{P_E} = \text{constant}\left(\frac{T_R}{T_E}\right)^{\frac{1}{2}} \frac{A_E}{A_R} . \quad . \quad . \quad (4)$$

From equations (2) and (4) the following expression is obtained:—

$$\frac{P_R}{P_E} = f\left\{ \begin{matrix} \text{Mach number} \\ \text{in pipe,} \end{matrix} \begin{matrix} \text{Flame} \\ \text{stabiliser} \\ \text{geometry,} \end{matrix} \frac{A_R}{A_E} \right\}$$

The Mach number in the pipe depends upon the ratio of reheat pipe area A_p and the effective throat area of the non-reheat engine nozzle A_E. Hence,

$$\frac{P_R}{P_E} = f\left\{ \frac{A_p}{A_E}, \frac{A_R}{A_E}, \begin{matrix} \text{Flame stabiliser} \\ \text{geometry} \end{matrix} \right\} .$$

This ratio is therefore constant for a given system.

REHEAT THRUST

The thrust from a choked reheat nozzle is, from equation (1),

$$X_R = \left[2\left(\frac{2}{\gamma_R+1}\right)^{\frac{1}{\gamma_R-1}} \frac{P_R}{p_0} - 1 \right] A_R p_0$$

The ratio of reheat thrust to non-reheat thrust is, therefore,

$$\frac{X_R}{X_E} = \frac{A_R}{A_E} \frac{\left[2\left(\frac{2}{\gamma_R+1}\right)^{\frac{1}{\gamma_R-1}} \frac{P_R}{P_E}\frac{P_E}{p_0} - 1 \right]}{\left[2\left(\frac{2}{\gamma_E+1}\right)^{\frac{1}{\gamma_E-1}} \frac{P_E}{p_0} - 1 \right]} .$$

Received 2nd January 1959.

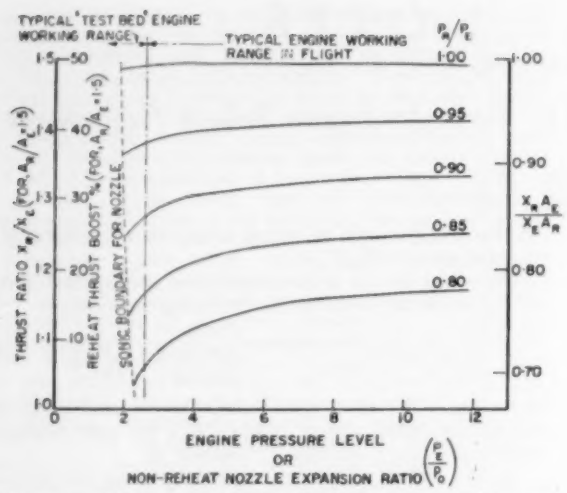

FIGURE 1. Reheat thrust boost. Engine pressure level curves for various pressure loss values.

That is,

$$\frac{A_E X_R}{A_R X_E} = f\left(\frac{P_R}{P_E}, \frac{P_E}{p_0}\right), \text{ neglecting any change in } \gamma_R \text{ and } \gamma_E.$$

The dependence of the thrust ratio upon (A_R/A_E) and (P_R/P_E) is generally appreciated but the dependence upon (P_E/p_0) is not. This relationship is shown graphically in Fig. 1 which shows the variation of thrust ratio with engine pressure level or non-reheat engine nozzle expansion ratio, for various reheat to non-reheat nozzle pressure ratios, with an arbitrary nozzle area ratio $(A_R/A_E)=1{\cdot}5$. A scale of the more general parameter $(A_E X_R)/(A_R X_E)$ is also shown.

REHEAT UNLIT OPERATION

By similar reasoning to that given for the reheat thrust ratio, it may be shown that,

$$\frac{X_U}{X_E} = \frac{A_U}{A_E} \frac{\left[2\left(\frac{2}{\gamma_E+1}\right)^{\frac{1}{\gamma_E-1}} \frac{P_U}{P_E}\frac{P_E}{p_0} - 1\right]}{\left[2\left(\frac{2}{\gamma_E+1}\right)^{\frac{1}{\gamma_E-1}} \frac{P_E}{p_0} - 1\right]}$$

where the suffix U denotes the nozzle in the "reheat system fitted but unlit" position.

If adiabatic, non-isentropic flow along the pipe is assumed, then,

$$\frac{A_U}{A_E} = \frac{P_E}{P_U}.$$

Therefore,

$$\frac{X_U}{X_E} = \frac{P_E}{P_U} \frac{\left[2\left(\frac{2}{\gamma_E+1}\right)^{\frac{1}{\gamma_E-1}} \frac{P_U}{P_E}\frac{P_E}{p_0} - 1\right]}{\left[2\left(\frac{2}{\gamma_E+1}\right)^{\frac{1}{\gamma_E-1}} \frac{P_E}{p_0} - 1\right]}$$

that is, $\frac{X_U}{X_E} = f\left(\frac{P_U}{P_E}, \frac{P_E}{p_0}\right)$, neglecting any change in γ_E.

This relationship is shown graphically in Fig. 2 which shows the variation of thrust loss with engine pressure level for various values of pressure loss when a reheat system is fitted but unlit.

CONCLUSIONS

Figure 1 shows that the thrust boost is most sensitive to engine pressure level at the lower end of the scale. This is important as the lower end is normally encountered on an engine test bed. It is observed that the pressure level effect is most pronounced on high pressure loss systems.

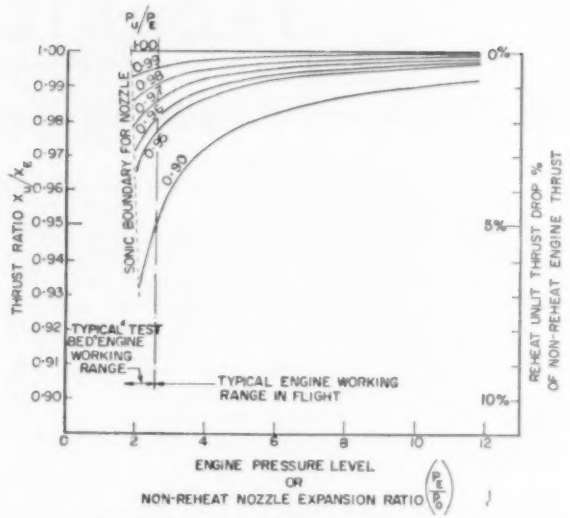

FIGURE 2. Reheat unlit thrust drop. Engine pressure level curves for various pressure loss values.

A similar effect is shown in Fig. 2. It is seen that the reheat unlit thrust drop is most sensitive to engine pressure level at the lower end of the scale and that this effect is most pronounced on high pressure loss systems.

Careful consideration should be given to engine pressure level when comparative tests are carried out on similar systems. The main factors which affect the engine pressure level on a test bed are,

(*i*) engine rating *i.e.* A_E.
(*ii*) corrected speed of engine.
(*iii*) general variations of pressure levels in different engines.

Hence, suitable corrections should be applied to the reheat thrust boost and reheat unlit thrust drop before the two test results are compared.

Finally, the data shown in Fig. 2 could be interpreted to apply to a non-reheat engine fitted with any type of system causing a pressure loss (such as a thrust reverser in the "forward" position), rather than a reheat system.

ACKNOWLEDGMENT

The author wishes to thank Rolls-Royce Ltd., Derby for permission to publish this technical note.

APPENDIX

THE DERIVATION OF EQUATION (1)

NOTATION

p_t static pressure at throat of nozzle.
a_t velocity of sound at throat of nozzle
ρ_t density of gas at throat of nozzle in absolute units
g acceleration of gravity

For one dimensional, isentropic, steady flow through a choked, convergent nozzle the thrust is given by the following momentum equation:—

$$X = \frac{M}{g} a_t + (p_t - p_0) A.$$

The continuity equation is,

$$\frac{M}{g} = \rho_t a_t A.$$

The velocity of sound equation is,

$$a_t^2 = \frac{\gamma p_t}{\rho_t}.$$

The momentum equation becomes

$$X = \gamma p_t A + (p_t - p_0) A$$
$$X = A\,[(\gamma+1)\,p_t - p_0]$$
$$X = A\left[2\left(\frac{2}{\gamma+1}\right)^{-1} p_t - p_0\right].$$

The pressure at the throat of a choked nozzle is related to the upstream total pressure thus,

$$\frac{p_t}{P} = \left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}}.$$

Substituting for p_t the following equation is obtained,

$$X = A\left[2\left(\frac{2}{\gamma+1}\right)^{\frac{1}{\gamma-1}} \frac{P}{p_0} - 1\right] p_0$$

REFERENCE

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A Note on Liquid and Solid Propellants for Rockets

by

E. G. D. ANDREWS, A.M.I.Mech.E. and A. W. T. MOTTRAM, B.Sc.

(*Armstrong Siddeley Motors Ltd.*)

DURING THE Second World War, a great many rockets were made and used operationally by both sides. By the end of the conflict, a pattern had begun to emerge. For applications where burning times were short and performance unimportant when compared with the need for simplicity, solid propellant rockets were used exclusively. Where control of thrust and the ability to start and stop repeatedly were involved, as in aircraft propulsion, or where performance was vital, as in the V2 ballistic missile, liquid propellants were applied. Since the war, this general pattern has persisted. There has been a progressive improvement in the performance of both types. At the same time, the thrust and total impulse of rockets have risen, until engines producing over one million pounds of thrust are envisaged.

One result of this progress has been a steady increase in the scope of solid propellant rockets. Some quite large missiles are now projected, one of which is designed to transport a small warhead over inter-continental distances. It is regrettable that in consequence, not a few persons, especially in the United States, have been tempted to assert that the day of the liquid propellant rocket is over and that everything can be done with solid propellants. There are signs that this attitude is on the wane in America, but it is still strong in this country.

It is difficult to understand why this should be so. The laws of physics and the realities of engineering imply a general division into zones of superiority which remains valid despite practical progress. This is because no amount of development will alter the facts, that a high pressure case weighs more than a low pressure tank, and that the weight of a liquid propellant engine cannot be reduced indefinitely. Although the dry weight of a solid propellant rocket increases more rapidly with burning time than that of a liquid propellant rocket, the weight of the liquid propellant engine remains essentially constant, however short the burning time.

In consequence we must expect to see liquid propellant used for the production of large thrusts for long durations and where accurate control of thrust, variability of thrust and thrust vector, together with repeated firings are required. We must expect to see solid propellant used where less stringent control of thrust and thrust vector is required and where its comparative simplicity is attractive. It will also be used where the increased weight of the case is offset by the saving in engine weight.

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The position of the boundary between solid and liquid propellant rockets has shifted about considerably since the war, and it will not stabilise until the temporary difficulties under which both systems now labour are overcome. The choice of propulsion systems will then be decided on the basis of the inherent properties of two types. As performance approaches the chemical limit, the highest specific impulse will be obtained from liquids. Above a certain size, the lower weight of tanks for liquids will give decisive superiority in overall performance in terms of altitude, range and velocity. Below that size, the solid propellant rocket will enjoy a large field of application. A similar argument applies to the problem of ground handling and tactical mobility. In small sizes, the simplicity of solid propellants gives a marked advantage. It is, however, easier to handle large rockets as an empty shell with the propellants in separate tankers. This arrangement is also safer when propellants are required in tonnage quantities.

There will, of course, be considerable overlapping between the two zones. This is because the boundary is in any case diffuse and more so because particular shortcomings in one system may be avoided on a short term basis by recourse to the other. It is quite likely that limitations in storage temperature of solid propellants may have promoted the work in hand in America on a liquid propellant propulsion system capable of being stored for long periods ready for instant use. Likewise the complication and poor readiness of current American liquid propellant ballistic missiles has stimulated the demand for *Polaris* and *Minuteman*. In this connection one may note a strong tendency for users to require a liquid propellant engine to carry out repeated firings at precisely controlled thrust, simply because it is practical to do so. Were solid propellants to be used, this would be accepted as impossible. This makes design for reliability more difficult with liquid propellants. In spite of this, it is within the authors' experience that the reliability of properly developed liquid propellant engines is high. The successful first flight of Black Knight has highlighted the reliability of its engine, already proven on the test bed.

We may expect then, that in the future, both solid and liquid propellant rockets will find increasing fields of application. The tendency will be for each to be used where its particular properties make it most suitable. The performance of both types will approach the chemical and physical limits and the standard of reliability will be set extremely high. The use of rocket propulsion will then become common-place, which is the ultimate aim of most engineering development.

Graduates' and Students' Section

Paris Aero Show Visit

As briefly reported in last month's JOURNAL we have arranged a weekend visit to Paris for the Aero Show at an all-in cost of only 10 guineas per person. Leaving London at 7 p.m. on Friday 19th June, the party will fly from Southend to Paris by Viking. Bed and breakfast hotel accommodation in Paris will be provided for the nights of 19th and 20th June, and the party will fly back on Sunday afternoon, reaching London by 7 p.m.

The charge for the visit covers coach travel to and from the airports in England and France, the return journey to Paris, the airport taxes in both countries and hotel accommodation in Paris.

Members who want to go on this visit should apply as soon as possible to J. R. Cownie, 40 Sherwood Avenue, Marshalswick, St. Albans, Herts., enclosing a deposit of £2. The balance of £8 10s. 0d. **must be sent by Friday 5th June,** a fortnight before the visit. Early application for this visit is advised as it is limited to 36 people and at the time of going to press the seats were selling fast.

The Deck Landing of Naval Jet Aircraft

On 25th February Lt. Cdr. D. J. Whitehead, Test Pilot of Blackburn and General Aircraft Ltd., gave a lecture on Deck Landing of Naval Jet Aircraft. The lecture, which was illustrated by slides, was given in two sections: Problems and Remedies.

One of the main problems involved in designing swept-wing aircraft, which can fly safely under full control at the low speeds required for deck landings, is that the combination of thin aerofoil sections for high speeds and high camber for low speeds can no longer be dealt with purely by the use of normal flap systems.

At high values of lift coefficient, swept wings tend to stall at the tips, and this results in pitch-up occurring in the slow speed approach configuration. Also the air flow over swept wings at high incidence tends to diverge towards the wing tip, resulting in a decrease of chord-wise flow over the ailerons which reduces their effectiveness.

With modern swept-wing aircraft having low thickness/chord ratios, high-incidence approaches are inevitable due to the shallow slope of the lift curve. With naval aircraft intended for operation from carriers it is essential that the pilot's view is almost perfect during landing because of the short length of runway available. The distance between the line of vision and the line of travel of the hook is an important measurement when calculating deck landing mirror angles and heights. Most current naval aircraft have small "hook to eye" distances, and it is possible to make successful deck landings without the aid of the mirror, but with more advanced types such as the Scimitar, the hook to eye distance is so great that landings must be made by mirror alone if the hook is to be placed within the wires. Furthermore, since the approach speed must be kept to within ± 2 knots of the optimum the pilot must keep a constant watch over both the A.S.I. and the mirror, and this introduces the considerable problem of pilot reaction time.

Lt. Cdr. Whitehead then dealt with various mechanical devices which are employed to remedy these problems.

Both stepped leading edges and wing fences can be used to prevent flow divergence and pitch-up, and to improve longitudinal stability. A drooped wing leading edge will lower the approach speed, as the flow is prevented from breaking away on the upper surface. Double-slotted flaps prevent flow break-away over the flap itself, when the wing is at high incidence, and this helps to prevent a drop in C_L. However, this device is now being superseded by the blown-flap in which the boundary layer is re-energised, resulting in an increase of $C_{L\,max.}$ and a decrease in the stalling speed.

Most difficulties concerned with high incidence approaches can be alleviated by employing a variable incidence wing as in the F8U Crusader. This solves the problems of view and loss of stability, and lessens the possibility of the tail striking the deck.

The problem of reaction time can be reduced by giving the pilot an aural airspeed indication during the final stages of the approach. This is still largely in the experimental stage.

The lecture dealt very fully with the problems involved, and ended with an interesting film on the "First flight of the Scimitar" and "Acceptance trials on H.M.S. Ark Royal" in which Lt. Cdr. Whitehead himself appeared.—J.G.

Lt. Cdr. Derek Whitehead.

Summer Party

A date for your diary is Friday 12th June, when we shall hold our Summer Party.

Annual General Meeting

At the Annual General Meeting on 4th March the existing committee were re-elected with the exception of Messrs Gibbins, Laker, Stewart and Tomlinson, who all resigned. Mr. Gibbins is moving down to Bristol, and Mr. Stewart leaves after many years' hard work for the committee to become an Associate Fellow. The new committee will take over in June and a list of the new members and their appointments will be given in the JOURNAL at that time.

Points which came out at the discussion included a suggestion that there should be more than two dances each year. The committee feel that even two involves them in a lot of hard work, but if there is a real demand for another, and a separate dance committee will organise it, it might be possible.

Another suggestion was that there should be more encouragement for Section members to visit aircraft companies farther away from London, and one way this could be done would be to arrange for a visit to coincide with a branch lecture which describes, or has some bearing on, the product of a local factory which we would subsequently look over. This would involve an overnight stop.

Comments on these suggestions would be very welcome, as would further ideas for lectures and visits.—D.T.R.

THE LIBRARY

Reviews

HIGH TEMPERATURE EFFECTS IN AIRCRAFT STRUCTURES. *N. J. Hoff (Editor). Pergamon Press, London, 1958. 357 pp. Illustrated. 70s.*

A series of books is currently being published for AGARD dealing with various aspects of the aeronautical sciences. This book (AGARDOGRAPH No. 28) is presented in sixteen chapters by various authors under the general editorship of N. J. Hoff.

The book is well printed and edited and the different chapters follow a planned logical sequence dealing with the various facets of the structural problem at elevated temperatures. Each chapter is self-contained, having its own notation and list of references.

The introduction briefly indicates the high temperature problems that have been and will be encountered in aircraft design and reviews aircraft development since the end of the Second World War. Despite the publication date of 1958 satellites are referred to in the future tense and the English Electric Thunderbird missile is described as having a liquid propellant motor and eight boosters!

In Chapter 2 by M. H. Bloom a useful review is made of the convective heat transfer processes for laminar and turbulent flow with pressure gradients; dissociation effects are also considered and the influence of radiation on heat transfer rates and temperature response is discussed for continuum, slip and free molecule flow. Finally, experimental methods using fluid flow, for simulated high speed, high temperature testing are discussed.

Most emphasis in Chapter 3 (by F. V. Pohle) is on heat conduction, and although internal radiation and convection effects are mentioned no results are presented showing their relative importance. A discussion of analytical and numerical methods of solving the heat conduction equation concludes the chapter.

Chapter 4, by P. Duwez, reviews the common metals used in aircraft design and also deals with refractory metals and non-metals. Aluminium and magnesium are dealt with jointly in two pages as also is steel and its alloys. On the other hand titanium and its alloys merit seven pages which rather unbalances the chapter. Criticism must be made of the fact that the significance of heating rates and heat soak periods is not mentioned.

Chapters 5 (by C. Gurney) and 6 (by I. Peyches) considered jointly embrace the whole field of aircraft non-metallic materials. There is some overlap between the two chapters when dealing with glass-reinforced plastics but no serious duplication. Reinforced and unreinforced plastics, adhesives and ceramics are considered in detail in Chapter 5 and Chapter 6 deals with various glasses and their fibres.

The problem of creep in metals is introduced in Chapter 7 (by N. P. Allen) and the various parameters affecting creep, strain-hardening and relaxation are discussed. The problems of determining, assessing and extrapolating creep data are also treated in detail. There is also a section on cermets and an appraisal of materials for short and long time heating applications up to 1200°C.

Chapter 8 (by W. N. Findley) does for plastics what Chapter 7 does for metals and the treatment is equally good. The various mechanical models are described which are considered to approximate the visco-elastic behaviour of materials. The influence of varying stress is discussed and the temperature-time superposition principle for correlating creep and stress relaxation data is considered.

Chapters 12 and 13 deal with the consequences of creep. The former deals generally with the methods of analysis for determining stress distributions in the presence of creep. Multiaxial states of stress and variable stress systems are discussed; also the elastic and plastic analogues for dealing with certain classes of problems. Chapter 13 reviews the creep buckling theories applicable to metallic materials buckling in the primary and secondary creep regions. The inclusion of instantaneous plastic deformations is given detailed consideration.

The effects of temperature on fatigue are well shown in Chapter 9 (by B. J. Lazan) and also the effects of dynamic creep under cyclic stress. The problem of resonance fatigue and its relation to material damping is also discussed. This paper deals only with metals.

Chapter 10 (by L. Broglio and P. Santini) presents the general equations of thermoelasticity and also studies the use of minimal principles in thermal stress analysis. Some emphasis is given to thermoelastic effects in typical wing structures and in discs and spheres. Also considered is the flat plate subjected to arbitrary temperature distributions allowing for arbitrary edge support conditions.

Chapter 11 is mainly concerned with two themes, torsional buckling of thin wings and flexural buckling of thin plates, although circular frames do have a small mention. For the thin wing analyses only linear theory is used and the alleviating effects of large deformation are not mentioned. There is also no reference to the problem of flexural instability. The plate analyses are more detailed and include consideration of post-buckling behaviour.

Chapter 14 investigates several wing static and dynamic aeroelastic phenomena in the presence of small and large temperature gradients and the problem of panel flutter is also discussed. Piston theory is used to evaluate the aerodynamic forces.

Experimental methods are discussed in chapter 15 (by J. Taylor), but in only ten pages little detail can be presented. Simple ovens are mentioned and power outputs are compared for electrical radiant heaters and electromagnetic induction heating units. Some of the high speed control and measuring techniques are discussed.

Chapter 16 (by R. R. Heldenfels) discusses in detail similarity parameters for scaling structural models. Analogs for determining temperature distributions are then discussed in which conductive, convective and radiative effects are included. Analog systems for determining directly the thermal stresses are also discussed.

It should be emphasised that each chapter is basically only a review. Only in particular cases are original solutions presented and the merit of each chapter is in drawing the reader's notice to those publications in the literature which merit further study. It would have been useful if a further chapter could have dealt with the structural and aerodynamic problems associated with ablation and sweat cooling and other possible topics also spring to mind. However, this publication should prove of use to all concerned in aircraft design and considering the paucity of books on this subject it is especially welcome.—D. J. JOHNS.

AVIATION MEDICINE—SELECTED REVIEWS (AGARDOGRAPH 25). *Advisory Group for Aeronautical Research and Development of the North Atlantic Treaty Organisation. Pergamon, London, 1958. 305 pp. Illustrated. 70s.*

This book is a collection of twelve papers on physiological research instruments and methods of measurement, selected for their actual or potential relevance to aviation problems. In other words, the title is appropriate as a librarian's classification, but is misleading to the extent that it suggests a "medical book" in the ordinary sense. The aim, according to the American editors, was to "document condensed sources of information summarizing specialized portions of the aeromedical and related sciences." They add, with some pride, that over seven hundred references are cited.

It is not surprising that five or six of the papers are concerned, directly or indirectly, with respiration. The change in density and composition of the atmosphere with height has, for over forty years, faced the aviation physiologist with his most urgent problem—and the one in which he may claim his greatest degree of success. Not all physiologists realise that their traditional methods would not have got very far without a solid theoretical basis—originally little more than the law of partial pressures. No such criticism can, however, be levelled at the contributors to this volume, one of whom illustrates a possible extension of the problem, namely, the rapid increase in ozone-concentration with height and the consequent risk, in certain circumstances, of toxic effects.

Another contributor enters into much interesting detail on the physical properties of aerosols. One suspects that this paper was gratefully accepted for its intrinsic merit rather than for any special relevance to aviation. The topic is not without relevance altogether, of course; for example, the behaviour of suspensions of radioactive particles will, in general, be affected by the atmospheric pressure. But it is not far from special pleading to propose that "automatic nebulization of the suitable (stimulant) drug triggered by loss of consciousness of the pilot" might be a valuable safety device. It is certainly feasible in principle, but there are simpler and better methods.

Other subjects reviewed (all, as already stated, chiefly from the point of view of research methods) are High Speed Motion Picture Photography, Stress Reactions (in Hans Selye's biochemical sense), Dosimetry of Ionising Radiations, Tissue Pathology, Temperature-Measuring Techniques and Pressure Transducers. There are several papers concerned with techniques of gas analysis, which may be regarded as coming under the general heading of Respiration.

As far as can be judged of such a wide variety of topics, the technical standard is high and the papers are well written and adequately indexed. A useful feature is the collection of summaries of all the papers in the introductory chapter compiled by the senior editor.

However, it must be emphasised that, various though the papers are, the editors clearly decided to make no attempt to cover more than a few of the major aspects of what is usually regarded as pertinent to aviation medicine. The book is, therefore, in no sense a textbook; but it has a certain homogeneity and uniformity in accordance with the curious policy of selection adopted, and it will undoubtedly be of use to specialists in search of what it has to offer. What is new will soon be old; what is old is far from moribund, and some of it is good enough to be counted as young for a long time to come. The force on a spherical particle suspended in a standing acoustic wave may or may not be a matter of aeronautical significance, but it has at least the youthful characteristic of being good fun.

What is not at all good fun is the listing of the references at the end of each paper (nearly 60 per paper, on the average), not in alphabetical or even chronological order, but just as the authors thought of them.—W. E. HICK.

MANUAL ON ROCKETS AND SATELLITES (Annals of the International Geophysical Year, Volume VI). *L. V. Berkner (Editor). Pergamon, London, 1958. 508 pp. Illustrated. £8.*

The complete programmes for the launching of research rockets and satellites during the International Geophysical Year are recorded in this book, with a wide selection of background literature on these topics. The rocket programme proceeded more-or less according to schedule, and the papers giving details of the programmes of each participating country form a most useful collection. The design of the rockets and the proposed experiments are described, with illustration and in the right degree of detail.

About 80 per cent of the book, however, is devoted to satellites, and this part is far less satisfactory, not through any fault of the editor or contributors, but through force of circumstance. The book was finally approved for publication (apart from some Appendices) by the 1957 C.S.A.G.I. conference at Washington, which ended on the day after the first Sputnik was launched. The papers therefore belong to the pre-satellite era, and very many of them assume that "the satellite," as it is so touchingly called, will be a 20 in. sphere weighing 21 lb. In fact sixteen satellites (including fragments such as nose cones) were placed in orbit during 1957 and 1958, and not one of them was of this size or weight. As a result, parts of the book have inevitably a dream-like air, and they serve as a useful warning to be sceptical of plans, however well-laid until they come to reality.

With this proviso, the book can be welcomed as the best set of specialist papers on satellites yet collected, even though some of these papers have now been superseded; it is particularly valuable to have so many Russian papers reprinted. All aspects of the subject are covered: orbital theory, visibility, optical and radio tracking methods, details of instrumentation for various experiments, description of launching vehicles, and many more. It is a pity however that the very first paper of the satellite section, on orbits, contains some serious errors, which could well have been corrected, since the paper was first published in 1956.

The listed satellite programmes of the various countries are less valuable because events have overtaken them. For example the puny *advertised* British contribution bears no relation whatever to the *actual* contribution.

The book is beautifully produced. The 254 illustrations and the type are clear and pleasingly laid out, and there are scarcely any misprints. It is also a happy example of the international co-operation which has been one of the best features of the I.G.Y.: Russian and American papers, printed in Britain, fraternise amicably.—D. G. KING-HELE.

AIRCRAFT AND MISSILE PROPULSION VOL. I—THERMODYNAMICS OF FLUID FLOW AND APPLICATION TO PROPULSION ENGINES. *M. J. Zucrow. John Wiley, New York, 1958. 538 pp. Illustrated. 92s.*

This book is the first of three volumes: the second will deal with the analysis of cycles and the performance characteristics of propulsion engines, and Vol. III with engine components. The preface states that "the prime objective of the work is to furnish the student with an understanding of the fundamental principles governing the functioning and operating characteristics of the engines employed for propelling high-speed aircraft and missiles."

This first volume has five chapters; " Review of fundamental principles; General characterisitics of propulsion systems; Thermodynamics of compressible fluid flow; Flow through nozzles; Flow through diffusers." There are twenty pages of tables, and eighty of problems, in toto 538 pages.

At first glance, the reviewer was favourably impressed. The book contains an enormous amount of information, and many worked examples. It has many illustrations and many references for further reading. It is well printed and bound. The field it covers is suitable for the intended graduate student. But on more detailed reading, the reviewer found a pervasive woolliness in the treatment. On p. 4 in a discussion of the "English absolute system" of units, the statement is made "By definition the unit of force is that force which imparts a unit acceleration, under standard gravity conditions, where the acceleration is g_0, to a unit mass." This sort of nonsense will scarcely prepare a student to find his way through the unit-jungle of modern engineering. Later on in the book, it is difficult to determine whether by "weight" the author means "local weight" or "standard weight." His statement of the steady-flow energy equation (p. 162) is given in a form which applies only under standard gravitational conditions. Surely in a work comprehending rocket engines the general form might be stated? In all chapters after the first, it appears that when the author writes g, he means what in the first chapter he calls g_0. There are other examples of carelessness over accuracy: in the diagram (p. 98) of air temperature distribution along a ram-jet intake, a continuous increase of temperature is shown associated with a stepwise variation of pressure, velocity and density; and on p. 106 a meaningless " energy balance " for a turbo-jet is given.

On p. 142 is written "the thrust developed by a rocket motor does not depend on a difference between the speeds of the jet and the propelled body." This puzzling statement, which is eventually understood in the context that jet speed is taken in a frame of reference moving with the propelled body, while the speed of the latter is taken in some other frame, is closely followed by a statement that "consequently, in theory at least, a body propelled by a rocket engine can travel at a speed higher than that of its exhaust gases."

There is much that is good in the book: its completeness and its profusion of examples make it useful for the teacher, while the student will be grateful for the background information, the detailed derivation of the formulae and the interweaving of theory and applications.—A. G. SMITH.

FUNDAMENTALS OF GAS DYNAMICS: Volume III of High Speed Aerodynamics and Jet Propulsion. *H. W. Emmons (Editor). Oxford University Press (Princeton University Press), London, 1958. 739 pp. Illustrated. 140s.*

This volume forms part of the twelve volume series on high speed aerodynamics and jet propulsion published by the Princeton University Press and contains eight separate parts by over a dozen distinguished authors as follows:—

Section A—The Equations of Gas Dynamics by H. S. Tsien.

Section B—One-Dimensional Treatment of Steady Gas Dynamics by L. Crocco.

Section C—One-Dimensional Treatment of Nonsteady Gas Dynamics by A. R. Kantrowitz.

Section D—The Basic Theory of Gas Dynamic Discontinuities by W. D. Hayes.

Section E—Shock Wave Interactions by H. Polachek and R. J. Seager.

Section F—Condensation Phenomena in High Speed Flows by H. Guyford Stever.

Section G—Gas Dynamics of Combustion and Detonation by Th. von Kármán, H. W. Emmons, R. S. Tankin and G. I. Taylor.

Section H—Flow of Rarefied Gases by S. A. Schaaf and P. L. Chambre.

Gas dynamics must be one of the fastest-growing branches of science. This conclusion is immediately obvious when a review of a volume of this size is undertaken; the conclusion is not, however, made from the material presented therein, but from the material known to be missing! It is inevitable that a book of this magnitude and complexity should suffer delays in publication but it is an unfortunate fact that it contains very few cited references later than 1955. Work done since that date has considerably advanced our knowledge of the topics treated in Sections E and C in particular. We note in the preface that Section C was prepared in 1952 and has not been subsequently revised; indeed, only a handful of references in this section are later than 1949. This section is particularly affected because, during the period 1950 to date, the shock tube has become the pre-eminent tool of experimental gas dynamics, mainly due to Dr. Kantrowitz's efforts in directing a large team of research workers at the AVCO Research Laboratory. Tremendous advances have been made in the understanding of very high speed gas dynamics; particularly relevant are the studies of the so-called " real gas " phenomena of dissociation and ionisation which Dr. Kantrowitz has pioneered.

One further critical observation might be made: parts of this volume overlap each other and much of Section G has been previously treated in another volume of this same series. On second thoughts however, this cannot be a valid criticism when the assiduous reader views a given problem from the differing standpoints of several world famous authorities on gas dynamics. The understanding of any problem can only be complete when all aspects have been considered.

Although Section H was, according to the preface, added as an afterthought to this volume, the authors are to be congratulated on a first-class account of the gas dynamic problems of rarefied gases. This section is a fascinating review of ingenious experimental and theoretical research by members of the leading group in rarefied gas dynamics.

This book contains a comprehensive account of the essentials of gas dynamics and should prove invaluable by providing graduate students with a solid foundation before undertaking research. Those engaged in extending the frontiers of gas dynamics will also find it refreshing to look anew from a different viewpoint at the basis of their current work but they should look elsewhere to find out the current " state of the art."—B. D. HENSHALL.

DIE ENTWICKLUNG DER FLUGZEUGE, 1914-1918. *Heinz Nowarra. J. F. Lehmanns, München, 1959. 143 pp. Illustrated. DM. 18. In German.*

The basic idea, layout and printing of this little book are so good that it is a great pity that the material contents leave so much to be desired.

The title is unfortunate, for the book does nothing to trace development of aeroplanes during the First World War. It consists principally of data tables giving brief dimensions, weights and performance figures for German, French, British, Italian, Austro-Hungarian and American aeroplanes; and there are brief notes on Japanese, Russian and Turkish aviation.

Perhaps the book's greatest value lies in its list of German aircraft of the war period: this section, although

by no means faultless, is probably more nearly complete and accurate than any of the others. There is, too, a useful list of the serial numbers of German naval aircraft; but one notes with surprise the author's statement that the individual numbers painted on German army machines were *Fabrikationsnummern* (construction numbers). They were not: they were order numbers laid down in the official contracts. Some of the items of information seem to have been included without much thought for evenness and consistency of presentation. Why, one wonders, are we treated to some (and only some) German projects, with drawings occupying space that might have been more sensibly used?

The author is in deep water when he tackles other nations' aircraft. At least eighty are missing from the British section alone; and of the 230-odd British types listed, only eleven have their wing area quoted. The "cruising speed," "landing speed," and "rate of climb" data columns are used so seldom throughout the book that they might as well have been omitted.

One could forgive some errors and omissions in the data tables (for the truly complete and wholly accurate reference work on aircraft of any period has yet to be written), but many of the illustrations are unspeakably bad. They have been retouched by someone who obviously knows nothing about aeroplanes and appears to have the finesse of an action painter. Their effect on the book is sadly detrimental.—J. M. BRUCE.

BONDED AIRCRAFT STRUCTURES. *C.I.B.A. (A.R.L.), Duxford, Cambridge, 1959. 177 pp. Illustrated. 52s. 6d.*

This is a collection of papers by users of metal bonding given after they have had some time to cool down. The happy exuberance of the early days has given way to a mood of sober appraisal. With hardly an exception the papers are informative without giving the impression of a sales brochure.

Following Dr. de Bruyne's "The Fundamentals of Adhesion" (which will be already familiar to all with more than a passing interest in adhesives) are two papers on Design Aspects. The first of these by Ljungstrom of S.A.A.B. would alone, to a design engineer, be worth the cost of the book. Practical design cases are dealt with faithfully using convincing test evidence. One sees for example that a bonded joint does not inevitably give much greater endurance than a riveted joint. It must be designed to do so. The same point is made by Van Beek of Fokker in the much briefer second paper on design, who emphasises the importance of detail design.

The remainder of the book (save for an exhaustive paper by Noton on Honeycomb Sandwich) is devoted to production and inspection. Bonding practice at de Havilland, Bristol, Short Brothers, Avro, Fokker, Sud-Aviation, Fairchild, and Chance Vought (not, alas, Glenn L. Martin) are covered. As might be expected, a wide variety of ways of applying heat and pressure are included. Although "Redux" bonding gets most attention, two papers are concerned with Araldite bonding and one with Araldite/glasscloth laminates.

On the subject of non-destructive testing there is little in the way of hard fact but a number of expressions of opinion. Only Noton appears convinced that a solution has been reached and he is somewhat reticent as to the method used (what is a Coinda-scope?).

It is disappointing that no author takes a really hard look at the question of costs although several give some examples. Only one paper gives "break even" numbers with riveting. Another disappointment is that no discussion is reported. Surely this must have been the most interesting part of the conference?

The book is fairly well produced and copiously illustrated. Indeed some of the photographs (such as those demonstrating the use of a weighing machine and a six inch rule) could well have been omitted.—N. K. GARDNER.

THEORY AND DESIGN OF MAGNETIC AMPLIFIERS. *E. H. Frost Smith. Chapman and Hall, London, 1958. 487 pp. Illustrated. 75s.*

This is the first book of a new series on Automation and Control Engineering, and a better topic to start with could not have been found. The use of magnetic amplifiers in control systems is now very wide-spread, chiefly on account of their inherent reliability. There are no mechanically moving parts nor fragile electronic heaters. They are instantly ready and usable, even after long periods of lying idle, stand up to rough treatment and work over a large temperature range. The disadvantages are largely being overcome by proper design and by appreciation of the limitations of the core materials. This is well brought out in this new and up-to-date book; speed of response, non-linearity of performance and non-reproducibility are all given full consideration.

The book starts with an introduction on magnetic materials and elementary analytical concepts associated with flux, inductance and induced e.m.f.'s. This is followed by a section on the transductor, historically the forerunner of magnetic amplifiers, but still required in many control applications. At every stage the fundamental principles are given, which enable the step by step procedure to be applied to obtain voltage and current wave forms.

Steady state and transient operation analysis of the various types of self and auto excited, biased and flux resetting magnetic amplifiers all form separate chapters in this fairly large (quarter of a million words) text. Of outstanding merit is the large section on the construction and design of these devices. This in itself will prove of inestimable value.

Concluding with a section on applications the book is fully comprehensive and will go far to meet all the needs of anyone concerned with magnetic amplifiers. It is well produced, illustrated with clear line drawings and has a good supply of original references.—I. C. WEST.

AERODYNAMIK DES FLUGZEUGES: Volume I. *H. Schlichting and E. Truckenbrodt. Springer, Germany, 1959. 455 pp. Illustrated. DM. 52.50. In German.*

There is always a need for a text which sets out the aerodynamic background to aircraft design. This book fulfils this purpose for classical aircraft layouts, omitting, however, some major subjects such as flight dynamics, aeroelasticity and aerodynamics of propulsion. The first volume contains the fundamentals of fluid dynamics and parts of aerofoil theory; a second volume, to follow, is intended to deal with wings of finite span as well as other parts of the aircraft, including interference effects. Altogether this book gives a thorough and lucid account of the fruits of some 50 years of research into the problems of aircraft engineering.

The first chapters on the physical properties of the atmosphere, hydrodynamics, gas dynamics, and boundary layers excel in presenting in a concise manner the essentials of the problems and their solutions. The physical aspects are kept well to the fore, as one would expect from the well-known first author and his work. The significant results are well brought out and admirably illustrated. The following chapters, introducing some aspects of aircraft

wings and dealing with aerofoil sections, give on the whole an equally well-balanced treatment as long as the more classical aspects of the problems are concerned. One would feel, however, that the presentation gets slightly out of focus, and that some matters are treated in rather more detail than their standing in the whole of the field would appear to warrant, when the more modern problems are considered. Thus the presentation of matters concerning three-dimensional boundary layers, viscous effects on aerofoils, and flow separations is not quite on the same level as that established in the earlier chapters; and in some cases personal preferences seem to dominate accounts of particular methods of solution. The description of practical section shapes and aircraft configurations may be, to some extent, misleading in suggesting design trends and engineering applications which would hardly bear closer scrutiny. These matters only begin to stand out as blemishes in a text which sets such a high standard of presentation as this one does in most of its contents.

Altogether it is good to be reminded that the state of the aerodynamics of the classical aircraft has been brought to such a level that books of such a standard of conciseness and penetration can be written.—D. KÜCHEMANN.

INTRODUCTION TO THE THEORETICAL AND EXPERIMENTAL ANALYSIS OF STRESS AND STRAIN. *A. J. Durelli, E. A. Phillips and C. H. Tsao. McGraw-Hill, New York, 1958. 498 pp. Illustrated. 97s.*

This book is not an "introduction" in the sense that it presents a simple, elementary statement of its subject, and yet it is indeed, as the authors claim, "an introduction to the field of stress analysis, giving an overall picture and a balanced description of the several methods used." Perhaps this claim should be modified at the moment, since this particular volume, being the first of an undefined number of projected volumes, covers only part of the whole field. Written primarily for use by "students with the background usually found in college seniors and undergraduates," this book should prove to be of considerable interest and value to the practising engineer, who wishes to have a better understanding of theoretical and experimental methods of stress analysis.

In Part 1, "Mathematical Method of Analysis," the authors have adopted the commendable procedure of starting from the general case and going to the particular case by simplification, rather than advancing from the simpler cases to the more difficult, and in consequence, have considered three-dimensional systems from the outset. This part, comprising nine chapters, contains an adequate summary of the relevant portions of the mathematical theory of elasticity, without being either a mere collection of formulae or an attempt to replace a conventional course in this subject. The first five chapters deal in a general manner with the theory of stress, the theory of strain, geometric representation of the state of stress and strain at a point, the theory of elasticity and applications to three dimensional problems. Chapter 6 proceeds to present the plane stress and plane strain approaches to two dimensional problems, together with a discussion of the limitations of these methods. The geometric representation of two dimensional stress and strain is dealt with in Chapter 7, which concludes with a useful section showing the representation of a particular state of stress and strain by the several methods discussed. The next chapter is devoted to a discussion of properties of special families of curves such as isoclinics, isochromatics, isostatics and others familiar to the users of photoelastic and brittle coating techniques. The final chapter in Part I covers the application of the preceding theory to two dimensional problems.

Part 2, "Introduction to the use of experimental stress analysis methods," is a most useful section, with chapters on fundamental concepts in strain measurements, statistical methods, and dimensional analysis.

Grid methods for the detection of surface strains are dealt with briefly but in a comprehensive manner in the single chapter of Part 3, and Part 4 contains what is probably the most complete account of brittle-coating methods yet published. The final section, Part 5, comprises a chapter on Mechanical Strain Gauges.

There is an excellent list of symbols, with dimensions quoted for all quantities. It might perhaps have been better if Mass rather than Force had been used, particularly since this is the case in Chapter 12.

The reviewer is disappointed only by the fact that photoelastic methods and electrical strain gauges must await a further volume (or volumes). It is sincerely hoped that the promise of the frontispiece, with its pictorial representation of the various methods, will be fulfilled in the not too distant future.—R. TATHAM.

Additions to the Library (see also page XXII Notices)

Aeronautical Engineering Index 1957. J. J. Glennon (*Editor*). 1959. Institute of the Aeronautical Sciences. 341 pp. $10 to members; $15 to non-members. This is the eleventh issue of this invaluable index.

Airline Price Policy. P. W. Cherington. Harvard University Press. (In U.K. Bailey Brothers and Swinfen.) 1958. 471 pp. Tables. 60s. A study of domestic airline passenger fares.

Artificial Satellites. A. Shternfeld. Office of Technical Services. 1958. 424 pp. $6. A translation prepared by the Technical Documents Liaison Office of Wright-Patterson Air Force Base of the original publication by the State Publishing House of Technical-Theoretical Literature, Moscow. Shternfeld was winner of the International Prize for the promotion of Astronautics. This is the second edition. The first preceded the launching of the Sputnik, this was written afterwards.

Daimler Airway, The: April 1922-March 1924. E. Birkhead. Offprint from *Journal of Transport History*. Nov. 1958. Leicester University Press. 6 pp. A history of one of the airlines absorbed by Imperial Airways.

Fifty Years Nearer the Sky. A. V. Roe and Co. Ltd. 1959. A 28 page illustrated pamphlet celebrating the firm's golden jubilee.

Ninth International Congress for Applied Mechanics. Volume VII. University of Brussels. 1957. £11 10s. 0d. for eight volumes. This volume completes the Proceedings of the Congress held in 1957 with three sections:—"Stabilité," "Ondes" and "Vibrations." These sections contain 12, 14 and 44 papers respectively. Nine are in French, one in German, and the rest in English.

Report of Special Meeting on Visual Aids to Flare Landing: Report of Study Group Meeting on Runway Lighting: Final Approach and Landing: Aircraft Performance: Factors Affecting Air-Traffic Control: Organization and Operation of Radio Telephony Networks: Long Distance Flights: Instrument Approach Landing. Publications of IATA between 1952-1958.

Rise of the Meritocracy, The: 1870-2033. Michael Young. Thames and Hudson. 1958. 160 pp. 15s. The author discusses today's educational policies and attempts to foresee their result in years to come.

Space Travel: Problems and Prospects. Wright-Patterson Air Field. Bibliography prepared by Technical Library.

Statistical Study of U.S. Civil Aircraft, as of 1st January 1958. U.S. Civil Aeronautics Administration. U.S.G.P.O. (H.M.S.O.). 41 pp. Tables. 2s. 8d. Detailed statistical data on all civil aircraft registered with C.A.A. on the date indicated.

Supersonic Transports (Proceedings). Institute of the Aeronautical Sciences. 1959. 47 pp. $1 to members; $2 to non-members. Sherman M. Fairchild Paper FF-20, comprising four papers on Commercial Air Transportation beyond the Subsonic Jets (Sebold); Operating the Supersonic Transport (Pennell); Supersonic Transports—Their Economics and Timing (Burton and Holmes) and Some Military Aspects of Supersonic Transports (Cartaino and others). These were read at the I.A.S Annual Meeting last January.

Who's Who in World Aviation and Astronautics. Marion E. Grambow (*Editor*). American Aviation. 1958. 497 pp. Described as Volume 2, this is actually the second edition of the reference work first published in 1955. Although inevitably with an American preponderance it is a useful guide to those prominent in the industry and associated sciences. The list of abbreviations gives R.Ae.S. as Royal Aeronautical National Society.

Reports

AERODYNAMICS

Boundary Layer

Couche limite turbulente: Corrélations spatio-temporelles et spectres de vitesses. A. Favre et al. O.N.E.R.A. Pub. 92. 1958.—(1.1.3.1).

Internal Flow—*See* Testing and Instruments

Loads—*See* Structures—Loads

Wings and Aerofoils

Note on the flow around delta wings with sharp leading edges. G. H. Lee. R. & M. 3070. 1958.—(1.10.2.2).

Testing and Instruments

Notes on some simple strain gauge networks commonly used with wind tunnel balances. J. R. Anderson. C.P. 415. 1959. Wheatstone bridge networks of four and of eight resistance strain gauges are considered from the point of view of the errors which may arise from the assumption of a linear relation between applied strain and bridge output. The effects of mismatch of initial resistance and gauge factor are examined.—(1.12.6.2×33.3.2).

An ejector for a hypersonic wind-tunnel. T. A. D'E. Thomson and Y. Y. Chan. A.R.L. Note A/170. *October* 1958. The performance of a small, central-blowing ejector was tested and related to the requirements of a hypersonic wind tunnel. The actuating and induced fluids were air and their stagnation temperatures were approximately equal. The optimum length of the mixing section, the effect of changing the axial position of the actuating nozzle relative to the entry cone and the performance at various actuating pressures were obtained.—(1.12.1.3×1.5.1.4).

Aperçu sur les possibilités expérimentales du tunnel hydrodynamique a visualisation de L'O.N.E.R.A. H. Werlé. O.N.E.R.A. NT. 48. 1958.—(1.12.1×17×1).

AGARD. wind tunnel calibration models. Specification 2. (*Supersedes AG4/M3.*) *Sept.* 1958. (*In English and French.*) The specifications are given of a series of standard models which may be used for calibrating aerodynamic testing facilities. Included are models designed to be tested under various conditions. A suggested test programme for each model is given and information required for comparative purposes.—(1.12.1).

AEROELASTICITY

See Structures—Loads

AIRCRAFT

See Structures—Theory and Analysis

AIRCRAFT OPERATION

See Aviation Medicine

EXTRA-ATMOSPHERIC TECHNOLOGY

Papers on the solar constant. Smithsonian Cont. to Astrophysics. Vol. 3, *No.* 3. 1958.—(8.1).

Ozone as a hazard in high altitude flying. E. W. C. Wilkins. AGARD Report 203. *Sept.* 1958. The high ozone content of the upper atmosphere as a hazard to high altitude flying, with possible methods of circumventing the problem, are discussed. The process of ozone formation and its seriousness as a biological hazard constitute the main part, and it is deduced that there is what may be called an "Ozone Barrier" extending from about 50,000 ft. to 150,000 ft. above the earth's surface.—(9×5×24).

METEOROLOGY

See Aviation Medicine

HYDRODYNAMICS

See Aerodynamics—Testing and Instruments

MATHEMATICS

On the zeros of Bessel functions considered as functions of order. J. Coulomb. A.R.L. Trans. 17. *Sept.* 1958.—(22.1).

POWER PLANTS

Laboratory and flight technique for the measurement of the temperature of turbine blading. E. P. Cockshutt et al. N.A.E. Report L.R.-229. *August* 1958. The evolution of a flight-worthy instrumentation system for measuring turbine rotor blade temperatures in an Orenda 14 turbo-jet engine is described.—(27.1.2).

STRUCTURES

Loads

Zusammenfassender Bericht über neuere Untersuchungen zur Frage der Böenbellastung von Flugzeugen. H. Krumhaar. Max-Planck-Institut. Mitt. No. 21. 1958. (*In German.*)—(33.1.2×1.6.3×2×31.2.1.2).

Theory and Analysis—*see also* Loads

Comparative strength tests of tension bolts with U.N.F. and B.S.F. threads (revised version of T.N. No. Structures 212). *R. F. Mousley et al. C.P.* 416. 1959. Results are given of comparative tests in tension of bolts with Unified Fine (UNF) and British Standard Fine (BSF) threads. Separate tests were made with ordinary nuts, with thin nuts, and with a pair of locknuts.—(33.2.4.13.1).

Graphical and tabulated data on the frequency and modal characteristics of swept cantilevers. A. H. Hall et al. N.A.E. Report 23. 1958. Comprehensive data on the frequency and modal characteristics are given which are of use in the application of semi-rigid analysis to preliminary design studies of missile and aircraft dynamics. Charts of frequency coefficients are given as a function of angle of sweep, aspect ratio, and rigidity ratio, together with interpolation tables covering the corresponding modes and running amplitude ratios (nodal co-ordinates). A brief discussion of profile camber is illustrated with experimental data, as are the charts and modal tables.—(33.2.3.2.10).

Testing—*see* Aerodynamics—Testing and Instruments

THERMODYNAMICS

Heat Transfer

The experimental examination of the local heat transfer on the surface of a sphere when subjected to forced convective cooling. J. Wadsworth. N.R.C. Report M.T.-39. *Sept.* 1958. The local heat transfer distribution on the isothermal surface of a sphere has been measured under forced convective cooling conditions over a range of Reynolds number of approximately 20,000 to 240,000, based upon sphere diameter. The results obtained in this range are compared directly with other work extant in the literature, and the discrepancies noted between the sets of results have been partially explained.—(34.3.2).

APPOINTMENTS

This section of THE JOURNAL *is available for advertisements of appointments in the Industry, the Ministries, Research Establishments, Universities and Colleges.*

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LOUGHBOROUGH COLLEGE OF TECHNOLOGY

Principal: H. L. HASLEGRAVE, Wh.Sc., M.A.(Cantab.), Ph.D.(London), M.Sc.(Eng.), M.I.Mech.E., M.I.Prod.E.

It is desired to fill a vacancy on the staff of the Department of Aeronautical Engineering. Applicants should be able to offer Applied Thermodynamics with particular reference to Aircraft Propulsion Units, together with Aerodynamics or Aircraft Structures. Industrial experience together with knowledge of the latest developments and techniques, would be an added advantage.

The grading of the appointment and commencing salary will depend upon qualifications and experience, and will be in accordance with the Burnham Technical Report.

Senior Lecturer Scale: £1,417 10s. × £52 10s.—£1,627 10s.
Lecturer Scale: £1,260 0s. × £31 10s.—£1,417 10s.

Further particulars and application forms may be obtained from The Registrar. (In reply please quote 3/A.O.).

UNIVERSITY OF SOUTHAMPTON

Applications are invited for the post of Research Assistant in the Department of Aeronautical Engineering. The successful applicant will be required to devote the whole of his time to research investigations relating to the design and performance of sailing yachts and will be expected to register for a Higher Degree. Applicants should possess a good First Degree in Engineering (including Aerodynamics) and should have an aptitude for experimental work. Some knowledge of sailing yachts and Naval Architecture would be an advantage.

Applications should be sent to the Secretary and Registrar, The University, Southampton, as soon as possible.

COVENTRY TECHNICAL COLLEGE

Principal:
A. J. RICHMOND, B.Sc.(Eng.)(Lond.), Ph.D., M.I.Mech.E.

Applications invited for following full time posts, duties to commence as soon as possible:—

(1) LECTURER in MECHANICAL ENGINEERING with special knowledge of Strength of Materials, or Theory of Machines, or Applied Thermodynamics.

(2) LECTURER in AERONAUTICAL ENGINEERING with special knowledge of Applied Aerodynamics and/or Aircraft Performance.

Applicants should be University Graduates and have had industrial experience. At least Graduate membership of appropriate professional body is required. Previous teaching experience is not essential. Burnham Technical Scale Salary (Men) £1,260—£1417 10s. per annum. Women will receive slightly less at present but equal pay will apply by 1961.

Further particulars and application forms from the Principal, Butts, Coventry, to whom applications should be submitted by **16th April 1959.**

W. L. CHIN,
Director of Education

THE COLLEGE OF AERONAUTICS
One Year Post-Graduate Course in the Physics and Mechanics of Structural Materials 1959-1960

Applications are invited for the one year course which begins on 5th October 1959. Prospective students must be of graduate status in an appropriate branch of science or engineering and must have practical experience in one of the fields covered by the course.

The purpose of the course is to give instruction in the analytical methods of the theories of elasticity and plasticity and in the basic theories of the nature of materials derived from the sciences of physics, chemistry and metallurgy.

Further information and forms of application may be obtained from: The Warden, The College of Aeronautics, Cranfield, Bletchley, Bucks.

SURREY EDUCATION COMMITTEE
Kingston Technical College, Fassett Road, Kingston-upon-Thames

Applications are invited for the post of SENIOR LECTURER in Aeronautical Engineering to specialise in Aero Structures, duties to commence as soon as possible. Salary scale £1,350 × £50 to £1,550 with 5% addition. London allowance payable.

Further particulars and application form on receipt of stamped addressed envelope from the Principal to be returned as soon as possible.

IMPERIAL COLLEGE

English Electric Studentship for research in Aeronautics, value £750 out of which fees must be paid. Further particulars from the Registrar, Imperial College, London S.W.7. Closing date **16th May 1959.**

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Salary range £1,050 to £1,500 per annum, according to qualifications and experience.

Replies, which will be treated in utmost confidence, should be addressed for the attention of the Staff Manager, Box 459, The Journal of the Royal Aeronautical Society, 1 Arundel Street, Strand, London, W.C.2.

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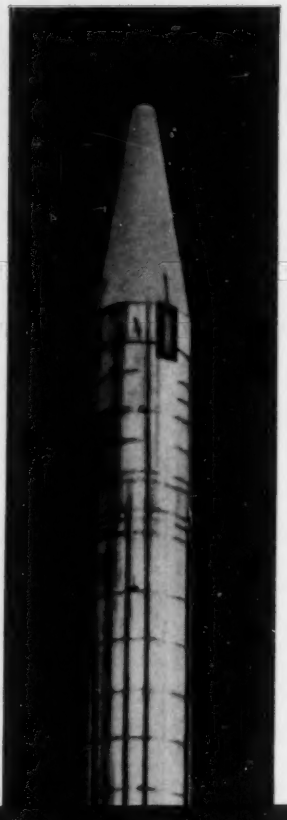

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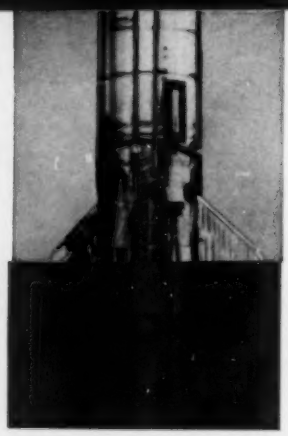

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